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GROUND SUPPORT EQUIPMENT TECHNOLOGY
LIGHTWEIGHT LAUNCHERS FOR SHOULDER-FIRED ROCKETS

FY71 ANNUAL REPORT

by

Wayne L. McCowan

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30 July 1971

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama

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ABSTRACT

The purpose of this report is to present and describe methods which may be used to define rocket exhaust flow fields, launch tube internal pressure profiles, recoil forces, and effects on missile launch due to launcher-missile interactions.

To this end, computer programs have been written which will calculate relevant data for input into other programs giving plots of the stagnation pressure and temperature profiles in a given rocket exhaust field. A program ~~has been~~ was written which will give a plot of internal tube pressure at the rocket nozzle exit plane as a function of missile travel. A method for estimating recoil is explained and a program, ~~has been~~ developed which simulates the launcher in the pitch plane for use in determining the launcher and missile motions in this plane and the effects on the missile of thrust misalignment and center of gravity offsets.

FOREWORD

Acknowledgement is made to Mr. Dean Christensen for his major contributions in writing the subject computer programs and to Mr. Billy Campbell for his contributions in the same vein.

CONTENTS

ILLUSTRATIONS

Section I. INTRODUCTION

The object of this task is to provide parameters and information relevant to the reduction in weight of shoulder fired rocket launchers to a minimum value consistent with the maintenance of required system performance.

The scope of this effort encompasses the following: (1) Preparation of computer programs to define the stagnation pressure and temperature profiles in the exhaust field of a rocket, (2) Develop a method for predicting the internal pressure in a launch tube during launch, (3) Discussion of means for estimating recoil forces, and (4) Establish a computer simulation program for predicting launcher effects on aiming and launching of the missile.

Section II. EXHAUST FLOW FIELD DEFINITION

2.1 Introduction

The overall purpose of the rocket exhaust flow field program is to provide, given all necessary data for a rocket, a visual representation of the stagnation pressure and stagnation temperature profiles in the rocket exhaust. Several programs are provided which calculate input data needed by the temperature and pressure programs.

The equations and methods upon which these programs are based are to be found in the references listed in the reference section. Each program will be shown listed on programming forms with input data shown in the appropriate registers and output values blocked in with dashed lines. A description will be given with each program giving its purpose, inputs, outputs and equations.

The machine for which these programs are written is the Hewlett-Packard 9100B with associated Plotter and Extended Memory units.

2.2 Symbol Definitions

a	-	Region I Boundary Coefficient
b	-	Region I Boundary Coefficient
c	-	Region I Boundary Coefficient
D_e	-	Nozzle Exit Diameter (inches)
D_t	-	Nozzle Throat Diameter (inches)
I_r	-	Intercept of Linear Spreading Characteristic Curve.
I_t	-	Intercept of Axial Temperature Decay Curve
K	-	Ratio of specific heats of exhaust products
l_s	-	Length of Supersonic Cone in Exhaust Flow (inches)
M_b	-	Maximum Mach Number at End of Region I
M_e	-	Exit Mach Number
m_p	-	Slope of Axial Pressure Decay Curve
m_t	-	Slope of Axial Temperature Decay Curve
P_c	-	Nominal Design Chamber Pressure (PSIA)
q	-	Value of Isobar to be Plotted
q_e	-	Gage Stagnation Pressure at Nozzle Exit (PSIG)
q_{ms}	-	Gage stagnation pressure on axis at end of supersonic cone (PSIG)
$q_{ms_{max}}$	-	Maximum value of pressure parameter for plot (PSIG)
r_1	-	Exhaust Plume Radius at End of Region I
SF_x	-	Plot Scale Factor for X-Axis
SF_y	-	Plot Scale Factor for Y - Axis
T	-	Value of isotherm to be plotted (^oF)
T_a	-	Ambient Temperature (^oF)
T_c	-	Flame Temperature of Propellant (^oF)

T_{max} - Maximum value of temperature parameter for plot (^oF)

X_{max} - Maximum value of distance parameter for plot

ΔX - Plot increment distance

θ_e - Nozzle expansion half angle (radians)

2.3 Exit Mach Number and Intercept of the Linear Spreading Characteristic Curve

2.3.1 Purpose

To calculate the Mach Number of the Exhaust Flow at the nozzle exit plane, and to determine the value of the linear spreading characteristic curve intercept. This last parameter is necessary in the generation of the Exhaust Pressure Plume Plot.

2.3.2 Inputs

D_e, D_t, K

2.3.3 Outputs

M_e, I_r

2.3.4 Equations

$$\frac{A_t}{A_e} = \frac{D_t^2}{D_e^2} = M_e\left[\frac{K+1}{2 + (K-1)\,M_e^2}\right]^{\frac{K+1}{2(K-1)}}$$

This equation is solved iteratively for M_e.

$$I_r = 0.15489201\,M_e^3 - 2.2941041\,M_e^2 + 10.612059\,M_e - 4.0070141 \quad \text{(Ref 3)}$$

2.3.5 Description

After program is entered the values of K, D_t, D_e are entered in the Z, Y, X registers respectively. Press Continue and the value for M_e will be displayed in the X, Y, Z registers. Press Continue twice and the value for I_r will be displayed in the X, Y, Z registers.

2.3.6 CALCULATION OF M_e AND I_R

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
1	1	01			
2	STOP	41	D_e	D_t	K
3	ROLL ↑	22			
4	x→( )	23			
5	d	17			
6	2	02			
7	4	04			
8	÷	35			
9	ROLL ↑	22			
a	x⇄y	30			
b	÷	35			
c	↓	25			
d	ROLL ↓	31			
10	x	36			
1	π	56			
2	x	36			
3	↓	25			
4	ROLL ↓	31			
5	x	36			
6	π	56			
7	x	36			
8	↓	25			
9	x⇄y	30			
a	÷	35			
b	y→( )	40			
c	c	16			
d	CONT	47			
20	3	03			
1	x→( )	23			
2	e	12			
3	CONT	47			
4	GO TO	44			
5	SUB	77			
6	7	07			
7	8	10			
8	CONT	47			
9	0	00			
a	CONT	47			
b	IF x>y	53			
c	6	06			
d	8	10			

Step	Key	Code	Display x	Display y	Display z
30	CONT	47			
1	e	12			
2	↑	27			
3	.	21			
4	0	00			
5	0	00			
6	5	05			
7	−	34			
8	y→( )	40			
9	e	12			
a	GO TO	44			
b	SUB	77			
c	7	07			
d	8	10			
40	CONT	47			
1	0	00			
2	CONT	47			
3	IF x<y	52			
4	3	03			
5	0	00			
6	CONT	47			
7	e	12			
8	↑	27			
9	.	21			
a	0	00			
b	0	00			
c	1	01			
d	+	33			
50	CONT	47			
1	y→( )	40			
2	e	12			
3	GO TO	44			
4	SUB	77			
5	7	07			
6	8	10			
7	CONT	47			
8	0	00			
9	CONT	47			
a	IF x>y	53			
b	4	04			
c	6	06			
d	CONT	47			

Step	Key	Code	Display x	Display y	Display z
60	e	12			
1	↑	27			
2	↑	27			
3	STOP	41	M_e	M_s	M_e
4	GO TO	44			
5	−	34			
6	0	00			
7	0	00			
8	e	12			
9	↑	27			
a	.	21			
b	1	01			
c	+	33			
d	y→( )	40			
70	e	12			
1	GO TO	44			
2	SUB	77			
3	7	07			
4	8	10			
5	GO TO	44			
6	2	02			
7	9	11			
8	e	12			
9	↑	27			
a	x	36			
b	d	17			
c	↑	27			
d	1	01			

Storage

Register	Contents
f	
e	M_e
d	K
c	$E = A_t / A_e$
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

CALCULATION OF M_e AND I_R

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
80	−	34				00	CONT	47				30	×	36			
1	↓	25				1	STOP	41	M_e	M_e	M_e	1	↓	25			
2	×	36				2	x→( )	23				2	+	33			
3	2	02				3	a	13				3	4	04			
4	+	33				4	×	36				4	.	21			
5	d	17				5	×	36				5	0	00			
6	↑	27				6	.	21				6	0	00			
7	1	01				7	1	01				7	7	07			
8	+	33				8	5	05				8	0	00			
9	↓	25				9	4	04				9	1	01			
a	x⇄y	30				a	8	10				a	4	04			
b	÷	35				b	9	11				b	1	01			
c	d	17				c	2	02				c	−	34			
d	↑	27				d	0	00				d	↓	25			
90	1	01				10	1	01				40	↑	27			
1	−	34				1	×	36				1	↑	27			
2	2	02				2	a	13				2	STOP	41	I_R	I_R	I_R
3	×	36				3	↑	27				3	END	46			
4	y→( )	40				4	×	36				4					
5	f	15				5	2	02				5					
6	d	17				6	.	21				6					
7	x⇄y	30				7	2	02				7					
8	1	01				8	9	11				8					
9	+	33				9	4	04				9					
a	f	15				a	1	01				a					
b	÷	35				b	0	00				b					
c	↓	25				c	4	04				c					
d	x⇄y	30				d	1	01				d					
a0	ln x	65				20	×	36									
1	×	36				1	↓	25									
2	↓	25				2	−	34									
3	e^x	74				3	a	13									
4	↑	27				4	↑	27									
5	e	12				5	1	01									
6	×	36				6	0	00									
7	c	16				7	.	21									
8	x⇄y	30				8	6	06									
9	−	34				9	1	01									
a	RETURN	77				a	2	02									
b	CONT	47				b	0	00									
c	CONT	47				c	5	06									
d	CONT	47				d	9	11									

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

2.4 Axial Temperature Decay Curve (with Plot)

2.4.1 Purpose

To generate values for the slope and intercept of the Axial Temperature Decay Curve.

2.4.2 Inputs

M_e, D_e, T_c, X_{max}, T_{max}
The values for X_{max} and T_{max} should be for a 6 in. by 9 in. plot.

2.4.3 Outputs

M_t, I_t
Plot of stagnation temperature on axis vs distance downstream on the axis.

2.4.4 Equations

$$-m_t = .020042599M_e^3 - .24382049M_e^2 + 1.0618553M_e + .11169953 \text{ (Ref 3).}$$

$$I_t = 6.36\ M_e - 2.874 \quad \text{(Ref 3).}$$

2.4.5 Description

After program has been entered, the values of M_e, D_e, T_c are entered in the Z, Y, X registers respectively. Press Continue and the value for M_t will be displayed in the Y register, value of I_t in the X register. Press Continue, then enter values for T_{max} and X_{max} in Y and X registers respectively for a 6 in. by 9 in. Plot. Press Continue for Plot.

2.4.6 AXIAL TEMPERATURE DECAY CURVE

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	FMT	42			
02	↑	27			
03	1	01			
04	STOP	41	T_c	D_e	M_e
05	x→( )	23			
06	b	14			
07	1	01			
08	2	02			
09	÷	35			
0a	y→( )	40			
0b	c	16			
0c	↓	25			
0d	y→( )	40			
10	d	17			
11	GO TO	44			
12	SUB	77			
13	—	34			
14	0	00			
15	0	00			
16	d	17			
17	↑	27			
18	x	36			
19	x	36			
1a	.	21			
1b	0	00			
1c	2	02			
1d	0	00			
20	0	00			
21	4	04			
22	2	02			
23	5	05			
24	9	11			
25	9	11			
26	x	36			
27	d	17			
28	↑	27			
29	x	36			
2a	.	21			
2b	2	02			
2c	4	04			
2d	3	03			

Step	Key	Code	Display x	Display y	Display z
30	8	10			
31	2	02			
32	0	00			
33	4	04			
34	9	11			
35	x	36			
36	↓	25			
37	—	34			
38	d	17			
39	↑	27			
3a	1	01			
3b	.	21			
3c	0	00			
3d	6	06			
40	1	01			
41	8	10			
42	5	05			
43	5	05			
44	3	03			
45	x	36			
46	↓	25			
47	+	33			
48	.	21			
49	1	01			
4a	1	01			
4b	1	01			
4c	6	06			
4d	9	11			
50	9	11			
51	5	05			
52	3	03			
53	+	33			
54	d	17			
55	↑	27			
56	6	06			
57	.	21			
58	3	03			
59	6	06			
5a	x	36			
5b	2	02			
5c	.	21			
5d	8	10			

Step	Key	Code	Display x	Display y	Display z
60	7	07			
61	4	04			
62	—	34			
63	2	02			
64	ROLL↓	31			
65	STOP	41	I_T	m_T	
66	x→( )	23			
67	+	33			
68	9	11			
69	y→( )	40			
6a	a	13			
6b	x⇄y	30			
6c	c	16			
6d	x	36			
70	y→( )	40			
71	e	12			
72	1	01			
73	5	05			
74	x	36			
75	y→( )	40			
76	d	17			
77	b	14			
78	x⇄y	30			
79	↑	27			
7a	3	03			
7b	ROLL↓	31			
7c	STOP	41			
7d	↑	27			

Storage	
f	ΔX
e	X_i (FEET)
d	M_e, X_{max} (FEET)
c	D_E (FEET)
b	T_c (°F)
a	m_T
9	I_T
8	
7	
6	
5	
4	
3	
2	
1	
0	

Step	Key	Code	Display x	y	z
80	4	04			
1	5	05			
2	0	00			
3	0	00			
4	x ⇄ y	30			
5	÷	35			
6	y → ( )	40			
7	−	34			
8	d	17			
9	GO TO	44			
a	−	34			
b	3	03			
c	2	02			
d	CONT	47			
-00	CONT	47			
1	1	01			
2	5	05			
3	0	00			
4	0	00			
5	↑	27			
6	0	00			
7	FMT	42			
8	↓	25			
9	3	03			
a	0	00			
b	0	00			
c	0	00			
d	↑	27			
-10	0	00			
1	FMT	42			
2	↓	25			
3	0	00			
4	↑	27			
5	0	00			
6	FMT	42			
7	↓	25			
8	1	01			
9	5	05			
a	0	00			
b	0	00			
c	FMT	42			
d	↓	25			

Step	Key	Code	Display x	y	z
-20	3	03			
1	0	00			
2	0	00			
3	0	00			
4	FMT	42			
5	↓	25			
6	4	04			
7	5	05			
8	0	00			
9	0	00			
a	FMT	42			
b	↓	25			
c	0	00			
d	FMT	42			
-30	↑	27			
1	RETURN	77			
2	↓	25			
3	3	03			
4	0	00			
5	0	00			
6	0	00			
7	x ⇄ y	30			
8	÷	35			
9	y → ( )	40			
a	−	34			
b	c	16			
c	e	12			
d	↑	27			
-40	.	21			
1	1	01			
2	x	36			
3	y → ( )	40			
4	f	15			
5	CONT	47			
6	e	12			
7	↑	27			
8	c	16			
9	÷	35			
a	x ← ( )	67			
b	+	33			
c	9	11			
d	x ⇄ y	30			

Step	Key	Code	Display x	y	z
-50	÷	35			
1	↓	25			
2	ln x	65			
3	↑	27			
4	a	13			
5	x	36			
6	↓	25			
7	e^x	74			
8	↑	27			
9	b	14			
a	x	36			
b	x ← ( )	67			
c	−	34			
d	c	16			
-60	x	36			
1	e	12			
2	↑	27			
3	x ← ( )	67			
4	−	34			
5	d	17			
6	x	36			
7	↓	25			
8	FMT	42			
9	↓	25			
a	RCL	61			
b	+	33			
c	y → ( )	40			
d	e	12			

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

AXIAL TEMPERATURE DECAY CURVE

Step	Key	Code	Display x	Display y	Display z
70	d	17			
1	IF x>y	53			
2	−	34			
3	4	04			
4	5	05			
5	CLEAR	20			
6	FMT	42			
7	↑	27			
8	END	46			
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

Register	Storage
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

2.5 Axial Pressure Decay Curve (with Plot)

2.5.1 Purpose

To generate values for the slope of the Axial Pressure Decay Curve and the length of the supersonic cone in the exhaust flow.

2.5.2 Inputs

M_e, D_e, P_c, K, X_{max}, $q_{ms_{max}}$

The dimensions of D_e should be in feet.

Values of X_{max} and $q_{ms_{max}}$ should be for a 6 in. by 9 in. Plot.

2.5.3 Outputs

l_s, m_p, q_e, q_{ms}

2.5.4 Equations

$$l_s = 16.113M_e - 16.125 \qquad \text{(Ref 3)}$$

$$m_p = -.451667M_e - 1.375 \qquad \text{(Ref 3)}$$

$$q_{ms} = 14.7 \left[\left(\frac{K+1}{2} \right)^{\frac{K}{K-1}} - 1 \right] \qquad \text{(Ref 3)}$$

$$q_e = P_c \left\{ \left[\frac{\frac{K+1}{2} M_e^2}{1 + \frac{K-1}{2} M_e^2} \right]^{\frac{K}{K+1}} \left[\frac{2K}{K+1} M_e^2 - \frac{K-1}{K+1} \right]^{\frac{1}{1-K}} \right\} - 14.7 \qquad \text{(Ref 3)}$$

2.5.5 Description

After program is entered, the values of M_e, D_e, P_c are entered in the Z, Y, X registers respectively. Press Continue, the value for l_s in feet will be displayed in the Z register, l_s in inches in the Y register, m_p in the X register. Press Continue, enter value of K in X register, press Continue. The value for q_{ms} will be displayed in the Z register, $(q_m/q_e)s$ in the Y, q_e in the X. Press Continue, then enter $q_{ms_{max}}$ in Y register, X_{max} in X register for a six inch by nine inch Plot. Press Continue for Plot.

2.5.6 AXIAL PRESSURE DECAY CURVE

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	FMT	42			
02	↑	27			
03	1	01			
04	STOP	41	P_c	D_e	M_e
05	x→( )	23			
06	c	16			
07	1	01			
08	2	02			
09	÷	35			
0a	y→( )	40			
0b	d	17			
0c	↓	25			
0d	y→( )	40			
10	e	12			
11	1	01			
12	6	06			
13	.	21			
14	1	01			
15	1	01			
16	3	03			
17	x	36			
18	1	01			
19	6	06			
1a	.	21			
1b	1	01			
1c	2	02			
1d	5	05			
20	−	34			
21	d	17			
22	x	36			
23	y→( )	40			
24	f	15			
25	e	12			
26	↑	27			
27	.	21			
28	4	04			
29	5	05			
2a	1	01			
2b	6	06			
2c	6	06			
2d	7	07			

Step	Key	Code	Display x	Display y	Display z
30	x	36			
31	1	01			
32	.	21			
33	3	03			
34	7	07			
35	5	05			
36	+	33			
37	↓	25			
38	CHG SIGN	32			
39	x→( )	23			
3a	0	00			
3b	CONT	47			
3c	1	01			
3d	2	02			
40	x	36			
41	x←( )	67			
42	0	00			
43	STOP	41	m_p	$\ell_{s\ IN.}$	$\ell_{s\ FT.}$
44	0	00			
45	↑	27			
46	↑	27			
47	2	02			
48	STOP	41	K		
49	x→( )	23			
4a	1	01			
4b	↑	27			
4c	↑	27			
4d	1	01			
50	+	33			
51	2	02			
52	÷	35			
53	ROLL ↑	22			
54	x⇄y	30			
55	1	01			
56	−	34			
57	x←( )	67			
58	1	01			
59	x⇄y	30			
5a	÷	35			
5b	x→( )	23			
5c	2	02			
5d	y→( )	40			

Step	Key	Code	Display x	Display y	Display z
60	3	03			
61	ROLL ↑	22			
62	ln x	65			
63	ROLL ↑	22			
64	x	36			
65	↓	25			
66	e^x	74			
67	↑	27			
68	1	01			
69	−	34			
6a	1	01			
6b	4	04			
6c	.	21			
6d	7	07			
70	x	36			
71	y→( )	40			
72	4	04			
73	x←( )	67			
74	2	02			
75	↑	27			
76	e	12			
77	x	36			
78	x	36			
79	2	02			
7a	+	33			
7b	x←( )	67			
7c	1	01			
7d	↑	27			

Storage

Register	Contents
f	ℓ_s
e	M_e
d	D_s (FEET)
c	P_c
b	
a	
9	
8	
7	
6	
5	U
4	q_{ms}
3	K/K-1
2	K-1
1	K
0	m_p

AXIAL PRESSURE DECAY CURVE

Step	Key	Code	Display x	Display y	Display z
8 0	1	01			
1	+	33			
2	e	12			
3	x	36			
4	x	36			
5	↓	25			
6	x ⇄ y	30			
7	÷	35			
8	y → ( )	40			
9	5	05			
a	x ← ( )	67			
b	1	01			
c	↑	27			
d	↑	27			
9 0	1	01			
1	+	33			
2	2	02			
3	ROLL ↑	22			
4	x	36			
5	↓	25			
6	x ⇄ y	30			
7	÷	35			
8	e	12			
9	x	36			
a	x	36			
b	x ← ( )	67			
c	2	02			
d	ROLL ↑	22			
a 0	÷	35			
1	↓	25			
2	−	34			
3	1	01			
4	↑	27			
5	x ← ( )	67			
6	2	02			
7	÷	35			
8	↓	25			
9	x ⇄ y	30			
a	ln x	65			
b	x	36			
c	↓	25			
d	e^x	74			
b 0	↑	27			
1	x ← ( )	67			
2	1	01			
3	↑	27			
4	x ← ( )	67			
5	2	02			
6	÷	35			
7	x ← ( )	67			
8	5	05			
9	ln x	65			
a	GO TO	44			
b	−	34			
c	0	00			
d	0	00			
-0 0	x	36			
1	↓	25			
2	e^x	74			
3	x ⇄ y	30			
4	÷	35			
5	c	16			
6	x	36			
7	1	01			
8	4	04			
9	•	21			
a	7	07			
b	−	34			
c	x ← ( )	67			
d	+	33			
-1 0	4	04			
1	x ⇄ y	30			
2	↑	27			
3	↓	25			
4	÷	35			
5	STOP	41	q_e	$\left(\frac{q_m}{q_e}\right)_s$	q_{ms}
6	0	00			
7	↑	27			
8	FMT	42			
9	↓	25			
a	1	01			
b	5	05			
c	0	00			
d	0	00			
-2 0	↑	27			
1	0	00			
2	FMT	42			
3	↓	25			
4	3	03			
5	0	00			
6	0	00			
7	0	00			
8	↑	27			
9	0	00			
a	FMT	42			
b	↓	25			
c	0	00			
d	↑	27			
-3 0	FMT	42			
1	↓	25			
2	1	01			
3	5	05			
4	0	00			
5	0	00			
6	FMT	42			
7	↓	25			
8	3	03			
9	0	00			
a	0	00			
b	0	00			
c	FMT	42			
d	↓	25			

Storage

Register	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

AXIAL PRESSURE DECAY CURVE

Step	Key	Code	Display x	Display y	Display z
40	4	04			
1	5	05			
2	0	00			
3	0	00			
4	FMT	42			
5	↓	25			
6	0	00			
7	FMT	42			
8	↑	27			
9	f	15			
a	↑	27			
b	y→()	40			
c	e	12			
d	.	21			
50	1	01			
1	x	36			
2	y→()	40			
3	f	15			
4	1	01			
5	0	00			
6	0	00			
7	x	36			
8	x←()	67			
9	+	33			
a	4	04			
b	↑	27			
c	3	03			
d	ROLL↓	31			
60	x⇄y	30			
1	STOP	41			
2	↑	27			
3	4	04			
4	5	05			
5	0	00			
6	0	00			
7	x⇄y	30			
8	÷	35			
9	y→()	40			
a	+	33			
b	d	17			
c	↓	25			
d	3	03			

Step	Key	Code	Display x	Display y	Display z
70	0	00			
1	0	00			
2	0	00			
3	x⇄y	30			
4	÷	35			
5	y→()	40			
6	+	33			
7	c	16			
8	CONT	47			
9	f	15			
a	↑	27			
b	1	01			
c	0	00			
d	x	36			
80	e	12			
1	÷	35			
2	↓	25			
3	ln x	65			
4	↑	27			
5	x←()	67			
6	+	33			
7	0	00			
8	x⇄y	30			
9	|y|	55			
a	x	36			
b	↓	25			
c	e^x	74			
d	↑	27			
90	x←()	67			
1	+	33			
2	4	04			
3	x	36			
4	c	16			
5	x	36			
6	e	12			
7	↑	27			
8	d	17			
9	x	36			
a	↓	25			
b	FMT	42			
c	↓	25			
d	RCL	61			

Step	Key	Code	Display x	Display y	Display z
a0	+	33			
1	y→()	40			
2	e	12			
3	↑	27			
4	1	01			
5	0	00			
6	0	00			
7	x	36			
8	↓	25			
9	IF x>y	53			
a	−	34			
b	7	07			
c	8	10			
d	CLEAR	20			
b0	FMT	42			
1	↑	27			
2	END	46			
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

Register	Contents
f	$\Delta x = .1\ell_c$
e	$x_i = \ell_c$
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

2.6 Boundary Coefficients (Region I)

2.6.1 Purpose

To generate coefficient values which determine the extent of the supersonic exhaust flow region (Region I).

2.6.2 Inputs

M_e, D_e, D_t, P_c, K, θ_e

2.6.3 Outputs

a, b, c, M_b, r_1

2.6.4 Equations

$$a = \frac{r_1 - r_e \sec w}{1 - \sec w} \qquad \text{(Ref 1)}$$

$$b = \operatorname{Tan} w \, (r_e - a) \qquad \text{(Ref 1)}$$

$$c = \left[(r_e - a)^2 + b^2\right]^{\frac{1}{2}} \qquad \text{(Ref 1)}$$

$$M_b = \left\{\frac{2}{K-1}\left[\left(\frac{P_c}{14.7}\right)^{\frac{K-1}{K}} - 1\right]\right\}^{\frac{1}{2}} \qquad \text{(Ref 1)}$$

$$r_1 = \frac{1}{2} D_t \sqrt{\frac{1}{M_b}} \left\{\frac{2}{K+1}\left[1 + \frac{M_b^2}{2}(K-1)\right]\right\}^{\frac{K+1}{4(K-1)}} \qquad \text{(Ref 1)}$$

2.6.5 Description

After program is entered, values for M_e, D_e, D_t are entered in Z, Y, X registers respectively. Press Continue, then enter P_c, K, θ_e in Z, Y, X registers respectively. Press Continue, and values for a, b, c will be displayed in the Z, Y, X registers respectively. Press Continue, values for M_b, r_1 will appear in Y, X registers respectively.

266 REGION I BOUNDARY COEFFICIENTS

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	FMT	42			
02	↑	27			
03	1	01			
04	STOP	41	D_o	D_e	M_e
05	x→()	23			
06	f	15			
07	y→()	40			
08	d	17			
09	↓	25			
0a	↓	25			
0b	x	36			
0c	1	01			
0d	−	34			
10	y→()	40			
11	e	12			
12	CONT	47			
13	2	02			
14	STOP	41	θ_e	K	P_c
15	x→()	23			
16	c	16			
17	y→()	40			
18	b	14			
19	↓	25			
1a	1	01			
1b	4	04			
1c	.	21			
1d	7	07			
20	÷	35			
21	↓	25			
22	ln x	65			
23	↑	27			
24	b	14			
25	↑	27			
26	1	01			
27	−	34			
28	b	14			
29	÷	35			
2a	↓	25			
2b	x	36			
2c	↓	25			
2d	e^x	74			

Step	Key	Code	Display x	Display y	Display z
30	↑	27			
31	1	01			
32	−	34			
33	2	02			
34	x	36			
35	b	14			
36	↑	27			
37	1	01			
38	−	34			
39	y→()	40			
3a	1	01			
3b	↓	25			
3c	÷	35			
3d	↓	25			
40	$\sqrt{x}$	76			
41	x→()	23			
42	+	33			
43	0	00			
44	x←()	67			
45	1	01			
46	↑	27			
47	x←()	67			
48	0	00			
49	x	36			
4a	x	36			
4b	2	02			
4c	÷	35			
4d	1	01			
50	+	33			
51	2	02			
52	x	36			
53	b	14			
54	↑	27			
55	1	01			
56	+	33			
57	y→()	40			
58	2	02			
59	↓	25			
5a	÷	35			
5b	↓	25			
5c	ln x	65			
5d	↑	27			

Step	Key	Code	Display x	Display y	Display z
60	x←()	67			
61	2	02			
62	↑	27			
63	x←()	67			
64	1	01			
65	÷	35			
66	4	04			
67	÷	35			
68	↓	25			
69	x	36			
6a	↓	25			
6b	e^x	74			
6c	↑	27			
6d	1	01			
70	↑	27			
71	x←()	67			
72	0	00			
73	÷	35			
74	↓	25			
75	$\sqrt{x}$	76			
76	x	36			
77	f	15			
78	x	36			
79	2	02			
7a	÷	35			
7b	y→()	40			
7c	b	14			
7d	x←()	67			

Storage

Register	Contents
f	D_o, a_ω, c
e	h, a
d	D_e, $(D_o/2) - a$
c	θ_e (RAD), f, ω, b
b	K, r_c
a	
9	
8	
7	
6	
5	
4	
3	
2	K+1
1	K−1, θ_e
0	M_e

REGION I BOUNDARY COEFFICIENTS

Step	Key	Code	x	y	z
80	1	01			
1	↑	27			
2	x←()	67			
3	2	02			
4	÷	35			
5	↓	25			
6	$\sqrt{x}$	76			
7	x→()	23			
8	f	15			
9	c	16			
a	x→()	23			
b	1	01			
c	x←()	67			
d	0	00			
90	↑	27			
1	x	36			
2	1	01			
3	−	34			
4	y→()	40			
5	c	16			
6	f	15			
7	x	36			
8	x	36			
9	ROLL ↓	31			
a	$\sqrt{x}$	76			
b	ARC	72			
c	TAN x	71			
d	ROLL ↓	31			
a0	f	15			
1	x	36			
2	e	12			
3	x	36			
4	ROLL ↓	31			
5	$\sqrt{x}$	76			
6	ARC	72			
7	TAN x	71			
8	−	34			
9	f	15			
a	GO TO	44			
b	−	34			
c	0	00			
d	0	00			

Step	Key	Code	x	y	z
+00	÷	35			
1	ROLL ↑	22			
2	$\sqrt{x}$	76			
3	ARC	72			
4	TAN x	71			
5	ROLL ↑	22			
6	+	33			
7	c	16			
8	$\sqrt{x}$	76			
9	ARC	72			
a	TAN x	71			
b	−	34			
c	x←()	67			
d	+	33			
+10	1	01			
1	+	33			
2	y→()	40			
3	c	16			
4	↓	25			
5	COS x	73			
6	↑	27			
7	b	14			
8	x	36			
9	d	17			
a	↑	27			
b	2	02			
c	÷	35			
d	↓	25			
+20	−	34			
1	c	16			
2	COS x	73			
3	↑	27			
4	1	01			
5	−	34			
6	↓	25			
7	÷	35			
8	y→()	40			
9	e	12			
a	d	17			
b	↑	27			
c	2	02			
d	÷	35			

Step	Key	Code	x	y	z
+30	↓	25			
1	x⇄y	30			
2	−	34			
3	y→()	40			
4	d	17			
5	c	16			
6	TAN x	71			
7	x	36			
8	y→()	40			
9	c	16			
a	d	17			
b	↑	27			
c	x	36			
d	c	16			
+40	↑	27			
1	x	36			
2	↓	25			
3	+	33			
4	↓	25			
5	$\sqrt{x}$	76			
6	x→()	23			
7	f	15			
8	↑	27			
9	e	12			
a	↑	27			
b	c	16			
c	ROLL ↑	22			
d	STOP	41	c	b	a

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

REGION I BOUNDARY COEFFICIENTS

Step	Key	Code	Display x	Display y	Display z
+5 0	x←( )	67			
1	+	33			
2	0	00			
3	↑	27			
4	↑	27			
5	b	14			
6	STOP	41	r_1	M_b	M_b
7	END	46			
8					
9					
a					
b					
c					
d					

2.7 Nozzle Placement

2.7.1 Purpose

To generate a representation of a nozzle as a visual aid when plotting pressure fields in the exhaust.

2.7.2 Inputs

θ_e, D_e, D_t, SF_x, SF_y

θ_e should be in degrees.

2.7.3 Outputs

Plot of nozzle

2.7.4 Description

After program is entered, enter θ_e, D_e, D_t, in Z, Y, X registers. Press Continue, enter SF_y, SF_x in Y, X registers. Press Continue to generate plot of nozzle.

27.5 NOZZLE PLACEMENT

PAGE 1 OF 1

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	FMT	42			
02	↑	27			
03	1	01			
04	STOP	41	D_t	D_e	θ_e
05	x→()	23			
06	f	15			
07	2	02			
08	÷	35			
09	y→()	40			
0a	e	12			
0b	f	15			
0c	x⇄y	30			
0d	2	02			
10	÷	35			
11	y→()	40			
12	f	15			
13	e	12			
14	x⇄y	30			
15	−	34			
16	↓	25			
17	x⇄y	30			
18	TAN x	71			
19	÷	35			
1a	2	02			
1b	CONT	47			
1c	STOP	41	SF_x	SF_y	
1d	ROLL ↑	22			
20	CHG SIGN	32			
21	x	36			
22	f	15			
23	ROLL ↑	22			
24	x	36			
25	y→()	40			
26	f	15			
27	x⇄y	30			
28	e	12			
29	x	36			
2a	y→()	40			
2b	e	12			
2c	0	00			
2d	FMT	42			

Step	Key	Code	Display x	Display y	Display z
30	↓	25			
31	f	15			
32	ROLL ↑	22			
33	FMT	42			
34	↓	25			
35	FMT	42			
36	↑	27			
37	x⇄y	30			
38	CHG SIGN	32			
39	x⇄y	30			
3a	FMT	42			
3b	↓	25			
3c	ROLL ↑	22			
3d	CHG SIGN	32			
40	x⇄y	30			
41	FMT	42			
42	↓	25			
43	FMT	42			
44	↑	27			
45	0	00			
46	↑	27			
47	FMT	42			
48	↓	25			
49	5	05			
4a	0	00			
4b	0	00			
4c	FMT	42			
4d	↓	25			
50	FMT	42			
51	↑	27			
52	6	06			
53	5	05			
54	0	00			
55	FMT	42			
56	↓	25			
57	6	06			
58	0	00			
59	0	00			
5a	FMT	42			
5b	↓	25			
5c	FMT	42			
5d	↑	27			

Step	Key	Code	Display x	Display y	Display z
60	6	06			
61	5	05			
62	0	00			
63	FMT	42			
64	↓	25			
65	1	01			
66	5	05			
67	0	00			
68	0	00			
69	FMT	42			
6a	↓	25			
6b	0	00			
6c	↑	27			
6d	FMT	42			
70	↑	27			
71	END	46			
72					
73					
74					
75					
76					
77					
78					
79					
7a					
7b					
7c					
7d					

Storage

Register	Contents
f	D_t, r_t, R_t
e	r_e, R_e
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

2.8 Boundary Plot (Region I)

2.8.1 Purpose

To generate a plot showing the extent of Region I in the rocket exhaust flow field.

2.8.2 Inputs

a, b, c, Δx, SF_x, SF_y

A good value for Δx is $\frac{b}{50}$.

2.8.3 Outputs

Plot showing the exhaust plume boundary in the supersonic region (Region I).

2.8.4 Equations

$$C^2 = (r-a)^2 + (x-b)^2 \qquad \text{(Ref 1)}$$

2.8.5 Description

After program is entered, values for a, b, c are entered in the Z, Y, X registers. Press Continue, then enter Δx, SF_y, SF_x in the Z, Y, X registers. Press Continue and a plot of the Region I Boundary will be generated.

2.8.6 REGION I BOUNDARY PLOT

Step	Key	Code	Display x	Display y	Display z
0 0	CLEAR	20			
1	FMT	42			
2	↑	27			
3	1	01			
4	STOP	41	c	b	a
5	x→()	23			
6	c	16			
7	y→()	40			
8	b	14			
9	↓	25			
a	y→()	40			
b	a	13			
c	CLEAR	20			
d	2	02			
1 0	STOP	41	SF_x	SF_y	Δx
1	x→()	23			
2	9	11			
3	y→()	40			
4	d	17			
5	↓	25			
6	y→()	40			
7	f	15			
8	CONT	47			
9	GO TO	44			
a	SUB	77			
b	6	06			
c	0	00			
d	d	17			
2 0	x	36			
1	e	12			
2	↑	27			
3	x←()	67			
4	9	11			
5	x	36			
6	↓	25			
7	FMT	42			
8	↓	25			
9	RCL	61			
a	+	33			
b	y→()	40			
c	e	12			
d	b	14			

Step	Key	Code	Display x	Display y	Display z
3 0	IF x>y	53			
1	1	01			
2	8	10			
3	CONT	47			
4	0	00			
5	↑	27			
6	FMT	42			
7	↑	27			
8	x→()	23			
9	e	12			
a	CONT	47			
b	GO TO	44			
c	SUB	77			
d	6	06			
4 0	0	00			
1	↓	25			
2	CHG SIGN	32			
3	↑	27			
4	d	17			
5	x	36			
6	e	12			
7	↑	27			
8	x←()	67			
9	9	11			
a	x	36			
b	↓	25			
c	FMT	42			
d	↓	25			
5 0	RCL	61			
1	+	33			
2	y→()	40			
3	e	12			
4	b	14			
5	IF x>y	53			
6	3	03			
7	a	13			
8	CLEAR	20			
9	FMT	42			
a	↑	27			
b	3	03			
c	STOP	41			
d	CONT	47			

Step	Key	Code	Display x	Display y	Display z
6 0	c	16			
1	↑	27			
2	x	36			
3	b	14			
4	↑	27			
5	x	36			
6	↓	25			
7	−	34			
8	e	12			
9	↑	27			
a	x	36			
b	↓	25			
c	−	34			
d	2	02			
7 0	↑	27			
1	e	12			
2	x	36			
3	b	14			
4	x	36			
5	↓	25			
6	+	33			
7	↓	25			
8	$\sqrt{x}$	76			
9	↑	27			
a	a	13			
b	+	33			
c	RETURN	77			
d					

Storage

f	Δx
e	x_i
d	SF_y
c	c
b	b
a	a
9	SF_x
8	
7	
6	
5	
4	
3	
2	
1	
0	

2.9 Pressure Plume Plot (Region II)

2.9.1 Purpose

To generate the isobar plots in the mixing region (Region II).

2.9.2 Inputs

I_r, b, D_e, l_s, r_1, Δx, SF_x, SF_y, $|m_p|$, q_{ms}, q_i

2.9.3 Outputs

Isobar plots for Region II of the exhaust flow.

2.9.4 Equations

$$\Delta x = (l_s - b).02 + 1\ (10^{-6})$$

$$r = r_s + r_e \left[\frac{(x/D_e)}{I_r}\right]^{1.16} \left[\frac{1}{1.35} \ln\left(\frac{q_m}{q}\right)\right]^{\frac{1}{2}} \left[1 - e^{-.2(x-b)}\right]$$

where

$$q_m = \left(\frac{l_s}{x}\right)^{|m_p|} q_{ms}$$

$$r_s = r_1 + Nr_e \left[\frac{(b/D_e)}{I_r}\right]^{1.16} - Nr_e \left[\frac{(x/D_e)}{I_r}\right]^{1.16}$$

$$Nr_e = r_1 \left[\frac{1}{\left[\frac{(l_s/D_e)}{I_r}\right]^{1.16} - \left[\frac{(b/D_e)}{I_r}\right]^{1.16}}\right]$$

2.9.5 Description

After program is entered, enter I_r, b, D_e in Z, Y, X registers. Press Continue, enter l_s, r_1, Δx in Z, Y, X registers. Press Continue, enter SF_y, SF_x, in Y, X registers. Press Continue, enter $|m_p|$, q_{ms}, q_i in Z, Y, X registers. Press Continue to generate plct of q_i. After each isobar is plotted, enter value for next q_i in X register and press Continue.

2.9.6 REGION II PRESSURE PLUME PLOT

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	STOP	41	D_e	b	I_R
02	x→()	23			
03	a	13			
04	y→()	40			
05	b	14			
06	÷	35			
07	↓	25			
08	y→()	40			
09	c	16			
0a	x⇄y	30			
0b	GO TO	44			
0c	SUB	77			
0d	−	34			
10	5	05			
11	2	02			
12	x→()	23			
13	0	00			
14	STOP	41	Δx	r_1	ℓ_s
15	x→()	23			
16	f	15			
17	y→()	40			
18	e	12			
19	↓	25			
1a	y→()	40			
1b	d	17			
1c	a	13			
1d	÷	35			
20	c	16			
21	GO TO	44			
22	SUB	77			
23	−	34			
24	5	05			
25	2	02			
26	↑	27			
27	x←()	67			
28	0	00			
29	−	34			
2a	e	12			
2b	x⇄y	30			
2c	÷	35			
2d	y→()	40			

Step	Key	Code	Display x	Display y	Display z
30	1	01			
31	x←()	67			
32	0	00			
33	x	36			
34	e	12			
35	+	33			
36	y→()	40			
37	2	02			
38	STOP	41	SF_x	SF_y	
39	x→()	23			
3a	−	34			
3b	a	13			
3c	y→()	40			
3d	−	34			
40	b	14			
41	STOP	41	q_i	q_{ms}	$\lvert m_{pl}\rvert$
42	x→()	23			
43	−	34			
44	c	16			
45	y→()	40			
46	−	34			
47	d	17			
48	↓	25			
49	y→()	40			
4a	−	34			
4b	e	12			
4c	SET FLAG	54			
4d	b	14			
50	x→()	23			
51	e	12			
52	e	12			
53	↑	27			
54	a	13			
55	÷	35			
56	c	16			
57	GO TO	44			
58	SUB	77			
59	−	34			
5a	5	05			
5b	2	02			
5c	x→()	23			
5d	−	34			

Step	Key	Code	Display x	Display y	Display z
60	f	15			
61	d	17			
62	↑	27			
63	e	12			
64	÷	35			
65	↓	25			
66	ln x	65			
67	↑	27			
68	x←()	67			
69	−	34			
6a	e	12			
6b	x	36			
6c	↓	25			
6d	e^x	74			
70	↑	27			
71	x←()	67			
72	−	34			
73	d	17			
74	x	36			
75	x←()	67			
76	−	34			
77	c	16			
78	÷	35			
79	↓	25			
7a	ln x	65			
7b	↑	27			
7c	1	01			
7d	.	21			

Storage

Register		
		—
f	Δx	z
e	r_1, x_i	$\lvert m_{pl}\rvert$
d	ℓ_s	q_{ms}
c	I_r	q
b	b	Y_{SF}
a	D_e	X_{SF}
9		
8		
7		
6		
5		
4		
3	K	
2	S	
1	N, r_2	
0	P	

REGION II PRESSURE PLUME PLOT

Step	Key	Code	Display x	Display y	Display z
80	3	03			
81	5	05			
82	÷	35			
83	↓	25			
84	$\sqrt{x}$	76			
85	↑	27			
86	x←()	67			
87	−	34			
88	f	15			
89	x	36			
8a	a	13			
8b	x	36			
8c	2	02			
8d	÷	35			
90	y→()	40			
91	3	03			
92	GO TO	44			
93	−	34			
94	6	06			
95	0	00			
96					
97					
98					
99					
9a					
9b					
9c					
9d					
a0	CONT	47			
a1	CONT	47			
a2	x←()	67			
a3	+	33			
a4	3	03			
a5	x	36			
a6	x←()	67			
a7	−	34			
a8	f	15			
a9	↑	27			
aa	x←()	67			
ab	+	33			
ac	1	01			
ad	x	36			

Step	Key	Code	Display x	Display y	Display z
10	x←()	67			
11	+	33			
12	2	02			
13	x⇄y	30			
14	−	34			
15	↓	25			
16	+	33			
17	x←()	67			
18	−	34			
19	b	14			
1a	x	36			
1b	e	12			
1c	↑	27			
1d	x←()	67			
20	−	34			
21	a	13			
22	x	36			
23	↓	25			
24	FMT	42			
25	↓	25			
26	d	17			
27	↑	27			
28	e	12			
29	IF x<y	52			
2a	−	34			
2b	4	04			
2c	7	07			
2d	x←()	67			
30	−	34			
31	b	14			
32	CHG SIGN	32			
33	x→()	23			
34	−	34			
35	b	14			
36	FMT	42			
37	↑	27			
38	IF FLAG	43			
39	GO TO	44			
3a	+	33			
3b	4	04			
3c	d	17			
3d	STOP	41	9:		

Step	Key	Code	Display x	Display y	Display z
40	x→()	23			
41	−	34			
42	c	16			
43	GO TO	44			
44	+	33			
45	4	04			
46	c	16			
47	RCL	61			
48	+	33			
49	y→()	40			
4a	e	12			
4b	GO TO	44			
4c	+	33			
4d	5	05			
50	2	02			
51	CONT	47			
52	÷	35			
53	↓	25			
54	ln x	65			
55	↑	27			
56	1	01			
57	•	21			
58	1	01			
59	6	06			
5a	x	36			
5b	↓	25			
5c	e^x	74			
5d	RETURN	77			

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

REGION II PRESSURE PLUME PLOT

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
60	e	12				0						0					
1	↑	27				1						1					
2	b	14				2						2					
3	−	34				3						3					
4	·	21				4						4					
5	2	02				5						5					
6	X	36				6						6					
7	↓	25				7						7					
8	CHG SIGN	32				8						8					
9	e^x	74				9						9					
a	CHG SIGN	32				a						a					
b	↑	27				b						b					
c	1	01				c						c					
d	+	33				d						d					
70	GO TO	44				0						0					
1	−	34				1						1					
2	0	00				2						2					
3	2	02				3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0											
1						1											
2						2											
3						3											
4						4											
5						5											
6						6											
7						7											
8						8											
9						9											
a						a											
b						b											
c						c											
d						d											

Storage	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

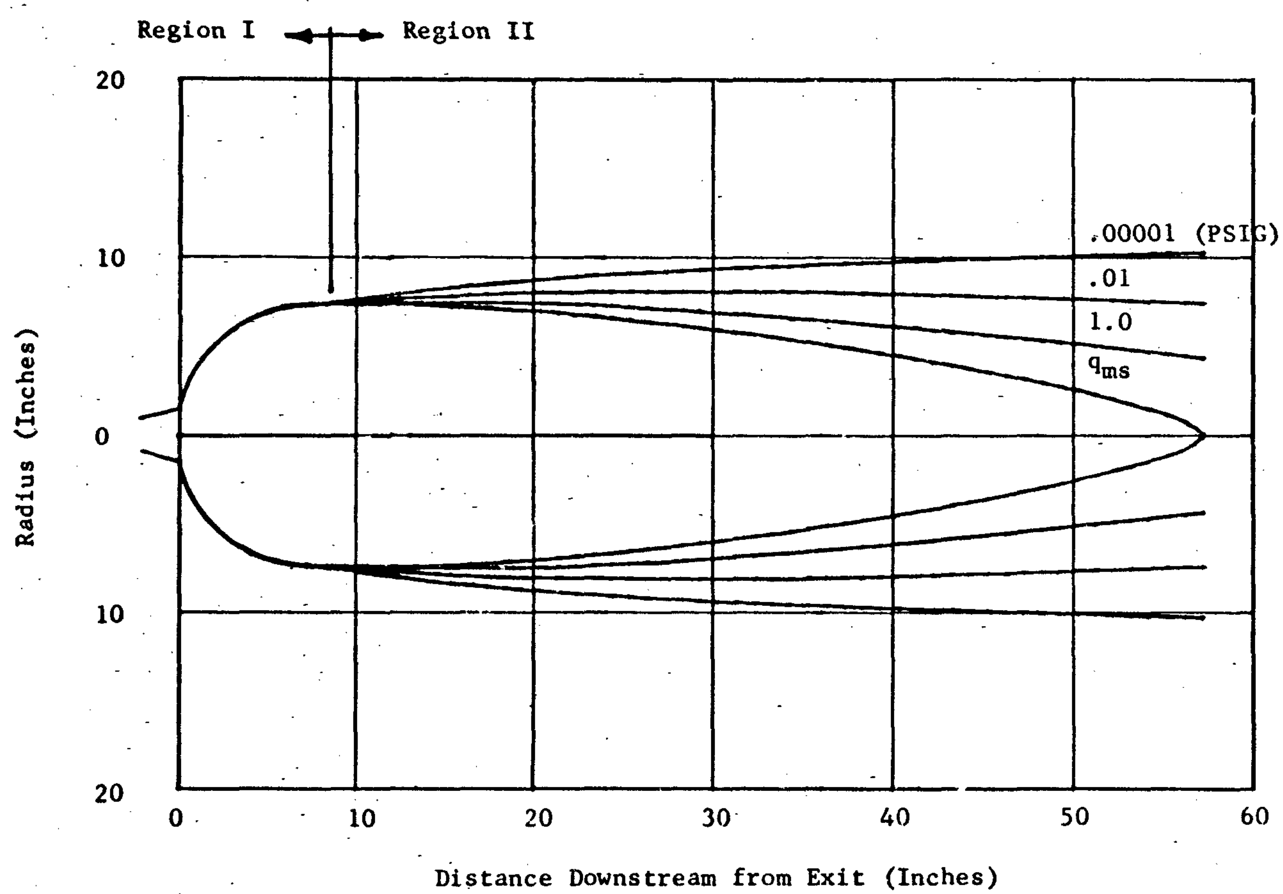

Figure 2-1 . Nozzle Placement, Region I Pressure Plume and Region II Pressure Plume

2.10 Pressure Plume Plot (Region III)

2.10.1 Purpose

To generate a plot of isobars in the subsonic exhaust flow region (Region III).

.10.2 Inputs

I_r, q_e, D_e, m_p, l_s, X_{max}, r_{max}, q, q_{ms}

Values of X_{max} and r_{max} should be for a five inch by fifteen inch plot.

2.10.3 Outputs

Isobar plots for downstream distances versus radial distances from center of nozzle exit.

2.10.4 Equations

$$r_o = r_e \left[\frac{(x/De)}{I_r} \right]^{1.16}$$

$$q_m = \left(\frac{l_s}{x} \right)^{|m_p|} q_{ms}$$

$$r = r_o \left[\frac{1}{1.35} \ln \left(\frac{q_m}{q} \right) \right]^{1/2}$$

2.10.5 Description

After program is entered, I_r, q_e, D_e are entered in Z, Y, X registers respectively. Press Continue, then enter m_p, l_s, q_{ms} in Z, Y, X registers respectively. Press Continue, then enter values of X_{max} and r_{max} for a five inch by fifteen inch plot. Press Continue, then enter in X register value of first isobar to be plotted. Press Continue for plot. Upon completion of plot, enter next isobar value and press Continue for plot.

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	FMT	42			
02	↑	27			
03	1	01			
04	STOP	41	D_e	q_e	I_R
05	y→()	40			
06	a	13			
07	x⇄y	30			
08	2	02			
09	÷	35			
0a	y→()	40			
0b	b	14			
0c	↓	25			
0d	y→()	40			
10	c	16			
11	CLEAR	20			
12	2	02			
13	STOP	41	q_{ms}	l_s	m_p
14	y→()	40			
15	0	00			
16	x→()	23			
17	d	17			
18	5	05			
19	x	36			
1a	y→()	40			
1b	e	12			
1c	CONT	47			
1d	↓	25			
20	y→()	40			
21	1	01			
22	CLEAR x	37			
23	.	21			
24	0	00			
25	0	00			
26	0	00			
27	5	05			
28	x→()	23			
29	−	34			
2a	c	16			
2b	GO TO	44			
2c	SUB	77			
2d	−	34			

Step	Key	Code	Display x	Display y	Display z
30	0	00			
31	0	00			
32	CONT	47			
33	3	03			
34	x⇄y	30			
35	↑	27			
36	e	12			
37	STOP	41			
38	↑	27			
39	7	07			
3a	5	05			
3b	0	00			
3c	0	00			
3d	x⇄y	30			
40	÷	35			
41	y→()	40			
42	2	02			
43	CONT	47			
44	2	02			
45	5	05			
46	0	00			
47	0	00			
48	ROLL ↑	22			
49	÷	35			
4a	y→()	40			
4b	3	03			
4c	x←()	67			
4d	0	00			
50	↑	27			
51	.	21			
52	1	01			
53	0	00			
54	x	36			
55	y→()	40			
56	f	15			
57	e	12			
58	x→()	23			
59	4	04			
5a	CONT	47			
5b	4	04			
5c	↑	27			
5d	↑	27			

Step	Key	Code	Display x	Display y	Display z
60	STOP	41	q		
61	x→()	23			
62	−	34			
63	c	16			
64	x←()	67			
65	0	00			
66	x→()	23			
67	e	12			
68	CONT	47			
69	GO TO	44			
6a	SUB	77			
6b	−	34			
6c	0	00			
6d	0	00			
70	GO TO	44			
71	SUB	77			
72	−	34			
73	6	06			
74	0	00			
75	x←()	67			
76	4	04			
77	IF x<y	52			
78	8	10			
79	4	04			
7a	↓	25			
7b	0	00			
7c	IF x=y	50			
7d	8	10			

Storage

Register	Contents	
f	Δx	
e	$5 l_s$, x_i	
d	q_{ms}	r_o
c	I_R	q_i
b	r_e	
a	q_e	
9		
8		
7		
6		
5		
4	$x_{max} = 5 l_s$	
3	SF_y	
2	SF_x	
1	m_p	
0	l_s	

REGION III PRESSURE PLUME PLOT

Step	Key	Code	Display x	Display y	Display z
80	4	04			
1	GO TO	44			
2	6	06			
3	8	10			
4	CLEAR X	37			
5	↑	27			
6	FMT	42			
7	↑	27			
8	x←( )	67			
9	+	33			
a	0	00			
b	x→( )	23			
c	e	12			
d	CONT	47			
90	GO TO	44			
1	SUB	77			
2	−	34			
3	0	00			
4	0	00			
5	↓	25			
6	CHG SIGN	32			
7	↑	27			
8	GO TO	44			
9	−	34			
a	8	10			
b	0	00			
c	CONT	47			
d	CONT	47			
+00	e	12			
1	↑	27			
2	b	14			
3	↑	27			
4	2	02			
5	x	36			
6	↓	25			
7	÷	35			
8	c	16			
9	÷	35			
a	↓	25			
b	ln x	65			
c	↑	27			
d	1	01			

Step	Key	Code	Display x	Display y	Display z
+10	.	21			
1	1	01			
2	6	06			
3	x	36			
4	↓	25			
5	e^x	74			
6	↑	27			
7	b	14			
8	x	36			
9	y→( )	40			
a	−	34			
b	d	17			
c	x←( )	67			
d	+	33			
+20	0	00			
1	↑	27			
2	e	12			
3	÷	35			
4	↓	25			
5	ln x	65			
6	↑	27			
7	x←( )	67			
8	+	33			
9	1	01			
a	x⇄y	30			
b	|y|	55			
c	x	36			
d	↓	25			
+30	e^x	74			
1	↑	27			
2	d	17			
3	x	36			
4	x←( )	67			
5	−	34			
6	c	16			
7	IF x>y	53			
8	5	05			
9	1	01			
a	÷	35			
b	↓	25			
c	ln x	65			
d	↑	27			

Step	Key	Code	Display x	Display y	Display z
+40	1	01			
1	.	21			
2	3	03			
3	5	05			
4	÷	35			
5	CONT	47			
6	CONT	47			
7	↓	25			
8	$\sqrt{x}$	76			
9	↑	27			
a	x←( )	67			
b	−	34			
c	d	17			
d	x	36			
+50	RETURN	77			
1	0	00			
2	↑	27			
3	RETURN	77			
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

REGION III PRESSURE PLUME PLOT

Step	Key	Code	Display x	Display y	Display z
60	X←()	67			
1	3	03			
2	X	36			
3	e	12			
4	↑	27			
5	X←()	67			
6	2	02			
7	X	36			
8	↓	25			
9	FMT	42			
a	↓	25			
b	↑	27			
c	RCL	61			
d	+	33			
70	y→()	40			
1	e	12			
2	RETURN	77			
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
80	GO TO	44			
1	SUB	77			
2	−	34			
3	6	06			
4	0	00			
5	X←()	67			
6	4	04			
7	IF X<Y	52			
8	9	11			
9	5	05			
a	↓	25			
b	0	00			
c	IF X=Y	60			
d	9	11			

Step	Key	Code	Display x	Display y	Display z
90	5	05			
1	GO TO	44			
2	+	33			
3	8	10			
4	d	17			
5	CLEAR X	37			
6	↑	27			
7	FMT	42			
8	↑	27			
9	GO TO	44			
a	+	33			
b	6	06			
c	0	00			
d	END	46			
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

Register	Value
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

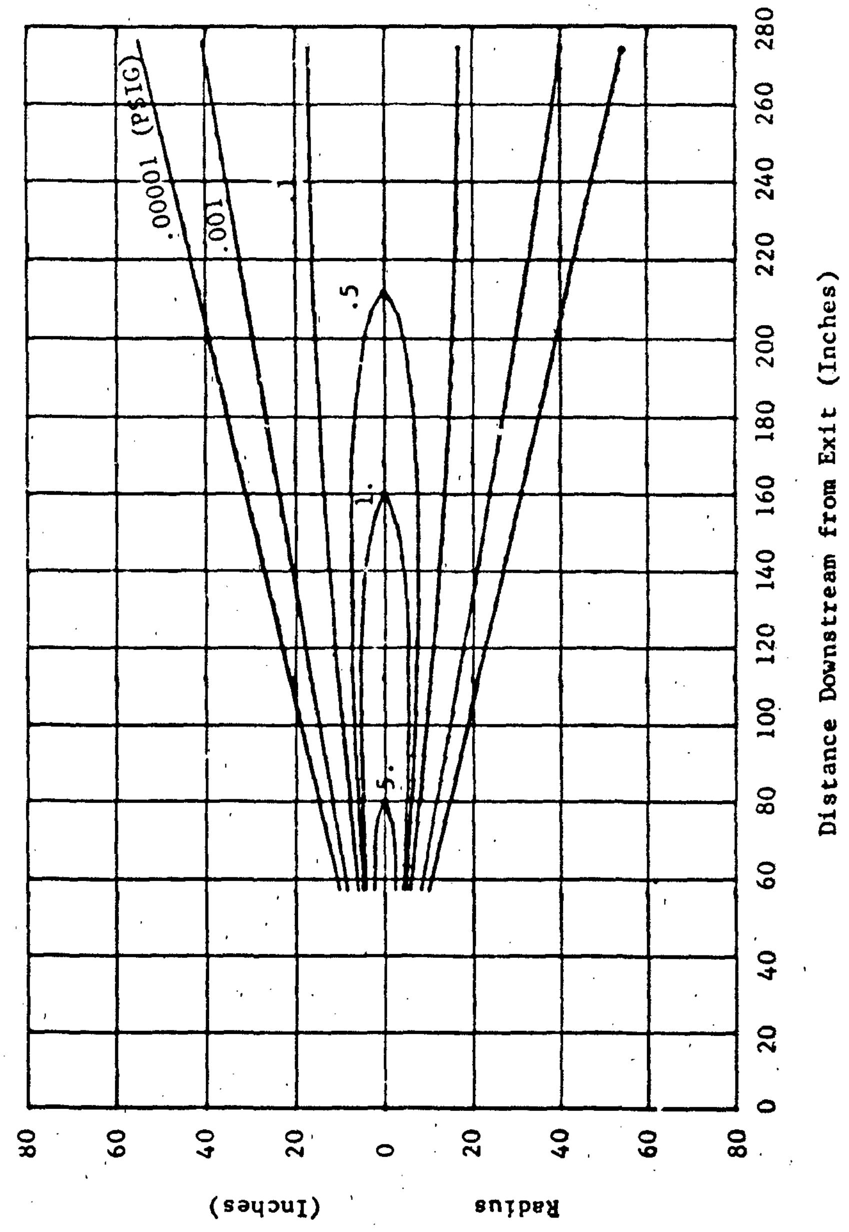

Figure 2-2. Pressure Plume Plot Region III

2.11 Calculation and Plot of Isotherms in Exhaust Field (Region II)

2.11.1 Purpose

To calculate and plot isotherms in the mixing region from the supersonic cone outwards.

2.11.2 Inputs

D_e, I_r, l_s, I_t, m_t, T_e, SF_x, SF_y, T_a, Δx, X, T

2.11.3 Outputs

T^*_{xs} - stagnation temperature on axis at end of supersonic cone.

Isotherms will be plotted on a radial versus axial distance scale.

2.11.4 Equations

$$T^*_{xs} = (T_c - T_a)\left[\frac{I_t}{(l_s/D)}\right]^{m_t} + T_a$$

$$r = \left[\frac{(X/D)}{I_r}\right]^{1.16}\left(\frac{r}{r_o}\right)(6D_e)$$

2.11.5 Description

This program is composed of five subprograms, P_o - P_4, which are entered into the Extended Memory Unit. The Printer should be on with the Y button depressed. After program is entered make all inputs as shown for P_o. Press Continue and a value will be printed for T^*_{xs}. Enter this value as shown for P_2 and the outline of the supersonic cone will be plotted. After each isotherm is plotted enter the value of the next isotherm to be plotted. These values must be less than T^*_{xs}. The curves will be drawn for the positive radius only.

2.11.6 REGION II EXHAUST FIELD ISOTHERM PLOT − P_o PAGE 1 OF 5

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20				30	e	12				0					
1	1	01				1	y→( )	40				1					
2	STOP	41	D_E	I_R	ℓ_s	2	−	34				2					
3	x→( )	23				3	0	00				3					
4	−	34				4	1	01				4					
5	f	15				5	FMT	42				5					
6	y→( )	40				6	GO TO	44				6					
7	−	34				7	END	46				7					
8	e	12				8						8					
9	↓	25				9						9					
a	y→( )	40				a						a					
b	−	34				b						b					
c	d	17				c						c					
d	2	02				d						d					
10	STOP	41	I_T	m_T	T_E	0						0					
1	x→( )	23				1						1					
2	−	34				2						2					
3	c	16				3						3					
4	y→( )	40				4						4					
5	−	34				5						5					
6	b	14				6						6					
7	↓	25				7						7					
8	y→( )	40				8						8					
9	−	34				9						9					
a	a	13				a						a					
b	3	03				b						b					
c	STOP	41	SF_x	SF_y	T_a	c						c					
d	x→( )	23				d						d					
20	−	34				0											
1	g	11				1											
2	y→( )	40				2											
3	−	34				3											
4	8	10				4											
5	↓	25				5											
6	y→( )	40				6											
7	−	34				7											
8	7	07				8											
9	4	04				9											
a	STOP	41	Δx	x		a											
b	x→( )	23				b											
c	f	15				c											
d	y→( )	40				d											

Storage

Register		
f	Δx	D_E
e	x_i	I_R
d		ℓ_s
c		I_T
b		m_T
a		T_E
9		SF_x
8		SF_y
7		T_a
6		
5		
4		
3		
2		
1		
0		

REGION II EXHAUST FIELD ISOTHERM PLOT – P_1

Step	Key	Code	Display x	Display y	Display z
00	x←( )	67			
01	−	34			
02	d	17			
03	↑	27			
04	x←( )	67			
05	−	34			
06	f	15			
07	÷	35			
08	x←( )	67			
09	−	34			
0a	c	16			
0b	x⇄y	30			
0c	÷	35			
0d	x←( )	67			
10	−	34			
11	b	14			
12	x⇄y	30			
13	ln x	65			
14	x	36			
15	↓	25			
16	e^x	74			
17	↑	27			
18	x←( )	67			
19	−	34			
1a	a	13			
1b	↑	27			
1c	x←( )	67			
1d	−	34			
20	7	07			
21	−	34			
22	↓	25			
23	x	36			
24	x←( )	67			
25	−	34			
26	7	07			
27	+	33	$\boxed{T^{\circ}_{25}}$		
28	PRINT	45			
29	PRINT	45			
2a	2	02			
2b	FMT	42			
2c	GO TO	44			
2d	END	46			

REGION II EXHAUST FIELD ISOTHERM PLOT - P_2

Step	Key	Code	Display x	Display y	Display z
00	5	05			
01	STOP	41	T		
02	X→()	23			
03	−	34			
04	6	06			
05	3	03			
06	FMT	42			
07	GO TO	44			
08	END	46			

Storage

REGION II EXHAUST FIELD ISOTHERM PLOT - P_3

Step	Key	Code	Display x	Display y	Display z
00	e	12			
1	↑	27			
2	x←()	67			
3	−	34			
4	f	15			
5	÷	35			
6	y→()	40			
7	d	17			
8	x←()	67			
9	−	34			
a	b	14			
b	x⇄y	30			
c	ln x	65			
d	x	36			
10	↓	25			
1	e^x	74			
2	↑	27			
3	x←()	67			
4	−	34			
5	6	06			
6	↑	27			
7	x←()	67			
8	−	34			
9	7	07			
a	−	34			
b	↓	25			
c	x	36			
d	x←()	67			
20	−	34			
1	c	16			
2	ln x	65			
3	↑	27			
4	x←()	67			
5	−	34			
6	b	14			
7	x	36			
8	↓	25			
9	e^x	74			
a	↑	27			
b	x←()	67			
c	−	34			
d	a	13			
30	x	36			
1	↓	25			
2	x⇄y	30			
3	÷	35			
4	↓	25			
5	ln x	65			
6	↑	27			
7	.	21			
8	5	05			
9	2	02			
a	÷	35			
b	↓	25			
c	$\sqrt{x}$	76			
d	x→()	23			
40	−	34			
1	5	05			
2	d	17			
3	↑	27			
4	x←()	67			
5	−	34			
6	e	12			
7	÷	35			
8	1	01			
9	.	21			
a	1	01			
b	6	06			
c	x⇄y	30			
d	ln x	65			
50	x	36			
1	↓	25			
2	e^x	74			
3	↑	27			
4	x←()	67			
5	−	34			
6	5	05			
7	x	36			
8	6	06			
9	x	36			
a	x←()	67			
b	−	34			
c	f	15			
d	x	36			
60	y→()	40			
1	−	34			
2	4	04			
3	4	04			
4	FMT	42			
5	GO TO	44			
6	END	46			

Storage

F	
E	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

REGION II EXHAUST FIELD ISOTHERM PLOT – P4 PAGE 5 OF 5

Step	Key	Code	Display x	Display y	Display z
00	e	12			
1	↑	27			
2	x←( )	67			
3	−	34			
4	d	17			
5	IF x<y	52			
6	2	02			
7	4	04			
8	x←( )	67			
9	−	34			
a	9	11			
b	×	36			
c	x←( )	67			
d	−	34			
10	4	04			
1	↑	27			
2	x←( )	67			
3	−	34			
4	8	10			
5	×	36			
6	↓	25			
7	x⇄y	30			
8	FMT	42			
9	↓	25			
a	RCL	61			
b	+	33			
c	y→( )	40			
d	e	12			
20	3	03			
1	GO TO	44			
2	2	02			
3	c	16			
4	FMT	42			
5	↑	27			
6	x←( )	67			
7	−	34			
8	0	00			
9	x→( )	23			
a	e	12			
b	2	02			
c	FMT	42			
d	GO TO	44			
30	END	46			

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

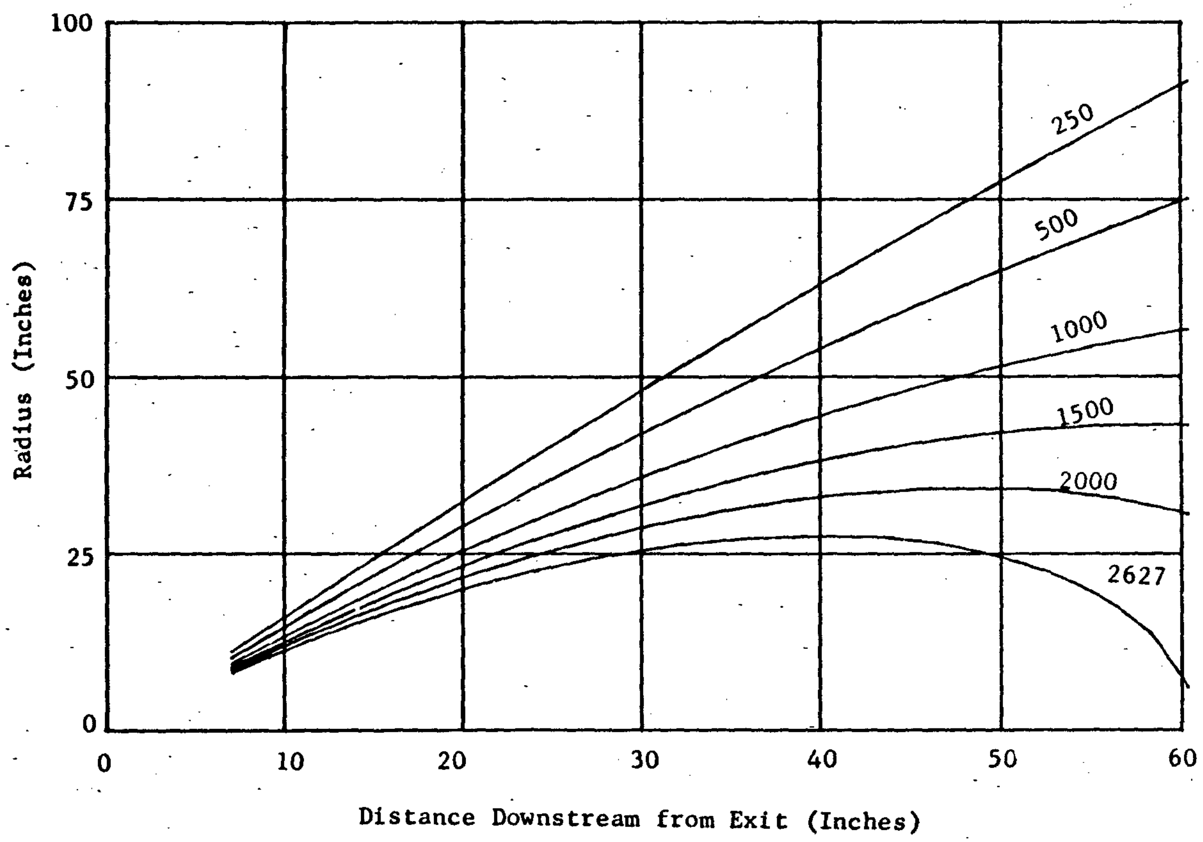

Figure 2-3. Isotherm Profile Plot Region II

2.12 Calculation and Plot of Isotherms in Exhaust Field (Region III)

2.12.1 Purpose

To calculate and plot isotherms in a rocket exhaust flow field in the region downstream of the end of the supersonic cone.

2.12.2 Inputs

D_e, I_r, l_s, I_t, m_t, T_c, SF_x, SF_y, Δx, X, T_a, T

2.12.3 Outputs

Isotherms will be plotted on a radial versus axial distance scale.

2.12.4 Equations

$$T = \left[e^{-.52\left(\frac{r}{r_o}\right)^2}\right]\left\{\left|T_c - T_a\right|\left[\frac{I_t}{(x/D_e)}\right]^{m_t} + T_a\right\}$$

$$r = \left(\frac{X}{D_e}\right)^{1.16}\left[\frac{6D_e^{1.16}}{I_r}\right]\left(\frac{r}{r_o}\right)$$

2.12.5 Description

After program is entered, all necessary inputs are made as indicated on program forms. For T, enter value of isotherm desired. After it is plotted enter next value of T and continue this procedure until plot is completed.

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	1	01			
02	STOP	41	D	I_R	ℓ_s
03	x→()	23			
04	d	17			
05	y→()	40			
06	c	16			
07	↓	25			
08	y→()	40			
09	−	34			
0a	a	13			
0b	2	02			
0c	STOP	41	I_T	m_T	T_c
0d	x→()	23			
10	b	14			
11	y→()	40			
12	a	13			
13	↓	25			
14	y→()	40			
15	−	34			
16	f	15			
17	3	03			
18	STOP	41	SF_x	SF_y	T_a
19	x→()	23			
1a	−	34			
1b	c	16			
1c	y→()	40			
1d	−	34			
20	b	14			
21	↓	25			
22	y→()	40			
23	−	34			
24	9	11			
25	4	04			
26	FMT	42			
27	↑	27			
28	STOP	41	Δx	x	
29	x→()	23			
2a	f	15			
2b	y→()	40			
2c	e	12			
2d	5	05			

Step	Key	Code	Display x	Display y	Display z
30	STOP	41	T		
31	x→()	23			
32	−	34			
33	d	17			
34	GO TO	44			
35	SUB	77			
36	5	05			
37	2	02			
38	0	00			
39	IF x>y	53			
3a	−	34			
3b	6	06			
3c	8	10			
3d	CLEAR X	37			
40	GO TO	44			
41	SUB	77			
42	8	10			
43	3	03			
44	GO TO	44			
45	SUB	77			
46	−	34			
47	1	01			
48	d	17			
49	RCL	61			
4a	+	33			
4b	y→()	40			
4c	e	12			
4d	GO TO	44			
50	3	03			
51	4	04			
52	b	14			
53	↑	27			
54	e	12			
55	↑	27			
56	d	17			
57	÷	35			
58	↓	25			
59	÷	35			
5a	a	13			
5b	x⇄y	30			
5c	ln x	65			
5d	×	36			

Step	Key	Code	Display x	Display y	Display z
60	↓	25			
61	e^x	74			
62	↑	27			
63	x←()	67			
64	−	34			
65	f	15			
66	↑	27			
67	x←()	67			
68	−	34			
69	9	11			
6a	−	34			
6b	↓	25			
6c	×	36			
6d	x←()	67			
70	−	34			
71	9	11			
72	+	33			
73	x←()	67			
74	−	34			
75	d	17			
76	CONT	47			
77	÷	35			
78	↓	25			
79	ln x	65			
7a	↑	27			
7b	.	21			
7c	5	05			
7d	2	02			

Storage

Register		—
f	Δx	T_c
e	x	r
d	D	T
c	I_R	SF_x
b	I_T	SF_y
a	m_T	ℓ_s
9		T_a
8		
7		
6		
5		
4		
3		
2		
1		
0	%	

REGION III EXHAUST FIELD ISOTHERM PLOT

Step	Key	Code	Display x	Display y	Display z
80	÷	35			
1	RETURN	77			
2	RETURN	77			
3	↓	25			
4	$\sqrt{x}$	76			
5	x→()	23			
6	0	00			
7	↑	27			
8	6	06			
9	x	36			
a	d	17			
b	x	36			
c	↑	27			
d	e	12			
90	x⇄y	30			
1	d	17			
2	÷	35			
3	1	01			
4	.	21			
5	1	01			
6	6	06			
7	x⇄y	30			
8	ln x	65			
9	x	36			
a	GO TO	44			
b	−	34			
c	0	00			
d	0	00			
100	↓	25			
1	e^x	74			
2	x	36			
3	↑	27			
4	x←()	67			
5	+	33			
6	c	16			
7	ln x	65			
8	x⇄y	30			
9	1	01			
a	.	21			
b	1	01			
c	6	06			
d	x	36			

Step	Key	Code	Display x	Display y	Display z
110	↓	25			
1	e^x	74			
2	x⇄y	30			
3	1	01			
4	x⇄y	30			
5	÷	35			
6	↓	25			
7	x	36			
8	y→()	40			
9	−	34			
a	e	12			
b	RETURN	77			
c	RETURN	77			
d	x←()	67			
120	−	34			
1	e	12			
2	↑	27			
3	x←()	67			
4	−	34			
5	b	14			
6	x	36			
7	↑	27			
8	x←()	67			
9	+	33			
a	e	12			
b	x⇄y	30			
c	x←()	67			
d	−	34			
130	c	16			
1	x	36			
2	↓	25			
3	FMT	42			
4	↓	25			
5	RETURN	77			
6	RETURN	77			
7	FMT	42			
8	↑	27			
9	x←()	67			
a	−	34			
b	a	13			
c	x→()	23			
d	+	33			

Step	Key	Code	Display x	Display y	Display z
140	e	12			
1	GO TO	44			
2	SUB	77			
3	+	33			
4	5	05			
5	2	02			
6	0	00			
7	IF x≥y	53			
8	−	34			
9	7	07			
a	b	14			
b	CLEAR x	37			
c	GO TO	44			
d	SUB	77			
150	+	33			
1	8	10			
2	3	03			
3	↓	25			
4	CHG SIGN	32			
5	x→()	23			
6	−	34			
7	e	12			
8	GO TO	44			
9	SUB	77			
a	−	34			
b	1	01			
c	d	17			
d	RCL	61			

Storage	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
60	+	33				0						0					
1	y→()	40				1						1					
2	+	33				2						2					
3	e	12				3						3					
4	Go To	44				4						4					
5	−	34				5						5					
6	4	04				6						6					
7	1	01				7						7					
8	0	00				8						8					
9	↑	27				9						9					
a	x←()	67				a						a					
b	+	33				b						b					
c	e	12				c						c					
d	↑	27				d						d					
70	x←()	67				0						0					
1	−	34				1						1					
2	c	16				2						2					
3	×	36				3						3					
4	↓	25				4						4					
5	FMT	42				5						5					
6	↓	25				6						6					
7	Go To	44				7						7					
8	−	34				8						8					
9	3	03				9						9					
a	7	07				a						a					
b	0	00				b						b					
c	↑	27				c						c					
d	x←()	67				d						d					
80	+	33				0											
1	e	12				1											
2	↑	27				2											
3	x←()	67				3											
4	−	34				4											
5	c	16				5											
6	×	36				6											
7	↓	25				7											
8	FMT	42				8											
9	↓	25				9											
a	Go To	44				a											
b	+	33				b											
c	2	02				c											
d	5	05				d											

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

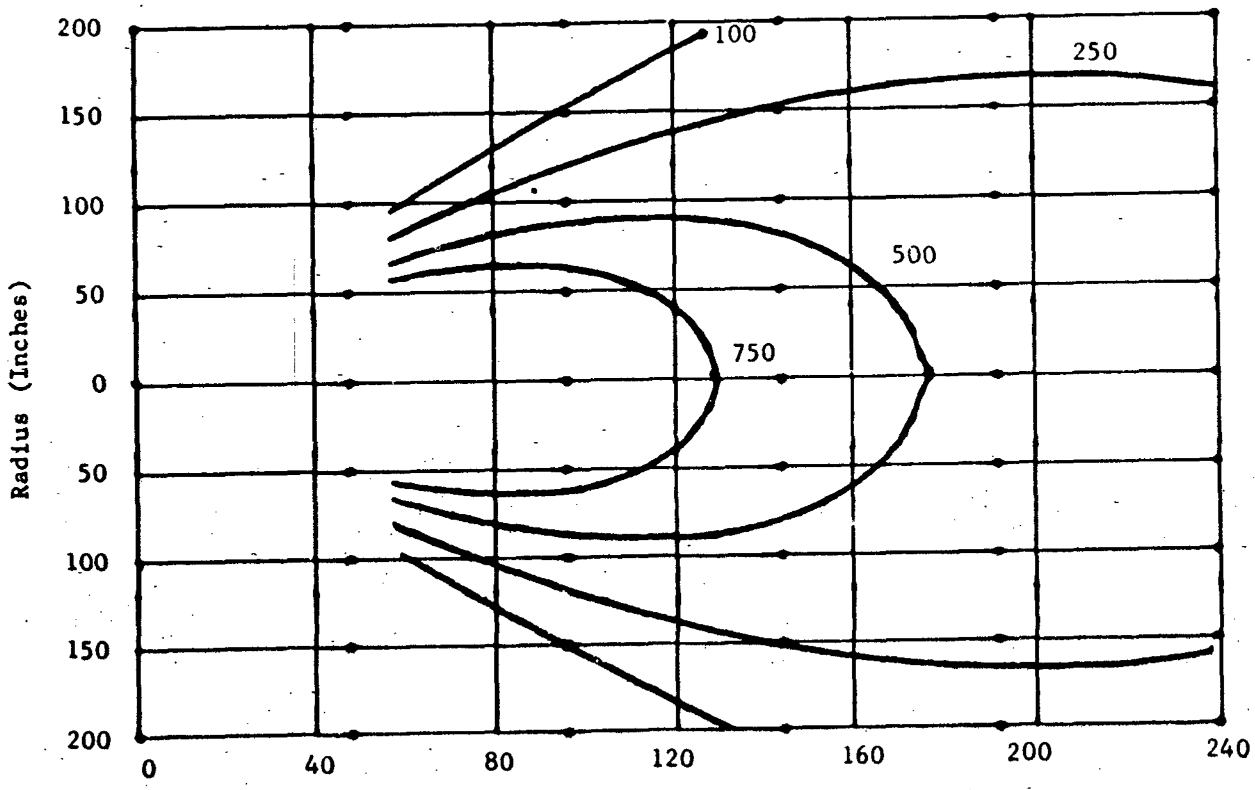

Figure 2-4 . Isotherm Profile Plot Region III

Section III. TUBE PRESSURE PROFILE AND RECOIL PREDICTION

3.1 Tube Pressure as a Function of Length

3.1.1 Discussion of Program

A method was developed whereby the pressure inside a launch tube due to missile exhaust gases could be predicted as a function of missile travel. The procedure used is discussed in the following.

A close fit was assumed between the missile motor nozzle and the walls of the launch tube, with no space available to allow the exhaust gases to expand around the nozzle rim in a forward direction. The pressure on the launch tube walls was thus assumed to be due to the component of exhaust gas flow parallel to the nozzle wall exerting a force on the launch tube walls. This program gives the pressure on the launch tube at the location of the rocket nozzle exit plane at the time the exit plane passes each given location.

This procedure does not account for shock wave buildup in the tube behind the nozzle nor for any effects attributable to them. This would be a consideration for future effort combining theoretical and test results.

3.1.2 Results and Discussion of Accuracy

The program as written will provide a prediction of tube pressure versus missile travel. The accuracy of the program will not be ascertainable until comparisons with actual test results can be performed.

The predictions may give lower than actual values since the effects of shock waves in the tube were not considered. Shock waves could cause pressure variations aft of the missile which may exceed predicted values. If test results seem to indicate this, a study could be undertaken to simulate shock wave effects.

3.1.3 Tube Pressure at Nozzle Exit Plane Versus Missile Travel

3.1.3.1 Purpose

To calculate and plot values for the pressure inside a launch tube, due to exhaust gases, at the nozzle exit plane as a function of missile travel.

3.1.3.2 Inputs

W - Effective Missile Weight (Pounds)
P_r - P_{ci}/thrust$_i$

P_{xy} - $(q_e + 14.7)/P_c$
θ_n - Nozzle half angle
t_n - Time
T_n - Thrust
Δt - Time increment
SF_y - Plot ordinate scale factor
SF_x - Plot abscissa scale factor

3.1.3.3 Outputs

Plot of tube pressure (PSIG) versus missile travel in tube (inches).

3.1.3.4 Description

After program is entered, enter P_{xy}, P_r, W in Z, Y, X registers. Press Continue, enter θ_n, SF_y, SF_x, in Z, Y, X registers. Press Continue, enter Δt in X register. Press Continue, enter T_n, t_n, in Y, X registers. Press Continue, value of (tube pressure, missile travel) will be plotted, continue entering values for T_n, t_n until plot is completed.

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	FMT	42			
02	↑	27			
03	1	01			
04	STOP	41	W	P_R	P_{xy}
05	y→()	40			
06	−	34			
07	e	12			
08	x⇄y	30			
09	3	03			
0a	2	02			
0b	•	21			
0c	2	02			
0d	÷	35			
10	1	01			
11	x⇄y	30			
12	÷	35			
13	y→()	40			
14	0	00			
15	↓	25			
16	y→()	40			
17	−	34			
18	f	15			
19	CLEAR	20			
1a	2	02			
1b	STOP	41	SF_x	SF_y	θ_M
1c	x→()	23			
1d	−	34			
20	d	17			
21	y→()	40			
22	−	34			
23	c	16			
24	ROLL ↑	22			
25	↑	27			
26	SIN X	70			
27	x⇄y	30			
28	COS X	73			
29	X	36			
2a	0	00			
2b	x→()	23			
2c	a	13			
2d	x→()	23			

Step	Key	Code	Display x	Display y	Display z
30	b	14			
31	y→()	40			
32	1	01			
33	x→()	23			
34	9	11			
35	x→()	23			
36	8	10			
37	CLEAR	20			
38	3	03			
39	STOP	41	Δt		
3a	x→()	23			
3b	f	15			
3c	CONT	47			
3d	0	00			
40	x→()	23			
41	2	02			
42	CONT	47			
43	a	13			
44	x→()	23			
45	c	16			
46	b	14			
47	x→()	23			
48	d	17			
49	CONT	47			
4a	x←()	67			
4b	+	33			
4c	2	02			
4d	↑	27			
50	1	01			
51	+	33			
52	y→()	40			
53	2	02			
54	↑	27			
55	STOP	41	t_n	T_n	
56	y→()	40			
57	b	14			
58	x→()	23			
59	a	13			
5a	SET FLAG	54			
5b	d	17			
5c	−	34			
5d	a	13			

Step	Key	Code	Display x	Display y	Display z
60	↑	27			
61	c	16			
62	−	34			
63	↓	25			
64	÷	35			
65	y→()	40			
66	3	03			
67	CONT	47			
68	GO TO	44			
69	SUB	77			
6a	−	34			
6b	0	00			
6c	0	00			
6d	CONT	47			
70	1	01			
71	2	02			
72	X	36			
73	x←()	67			
74	−	34			
75	d	17			
76	X	36			
77	e	12			
78	↑	27			
79	c	16			
7a	GO TO	44			
7b	−	34			
7c	3	03			
7d	3	03			

Storage

Register		
f	Δt	$\bar{P}_{xy}$
e	t_i	P_R
d	T_{n-1}	X_{SE}
c	t_{n-1}	Y_{SE}
b	T_n	
a	t_n	
9	$\dot{x}_{n-1}$	
8	X_{n-1}	
7		
6		
5		
4		
3	m_n	
2	n	
1	$\sin\theta_M \cos\theta_M$	
0	1/M	

TUBE PRESSURE AT NOZZLE EXIT

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
1	e	12			
2	↑	27			
3	c	16			
4	−	34			
5	x⇄y	30			
6	↑	27			
7	x	36			
8	x	36			
9	x⇄y	30			
a	↑	27			
b	x←( )	67			
c	+	33			
d	3	03			
10	x	36			
1	6	06			
2	÷	35			
3	↓	25			
4	ROLL ↓	31			
5	x	36			
6	d	17			
7	x	36			
8	2	02			
9	÷	35			
a	↓	25			
b	+	33			
c	x←( )	67			
d	+	33			
20	0	00			
1	x	36			
2	e	12			
3	↑	27			
4	c	16			
5	−	34			
6	x←( )	67			
7	+	33			
8	9	11			
9	x	36			
a	x←( )	67			
b	+	33			
c	8	10			
d	+	33			

Step	Key	Code	Display x	Display y	Display z
30	↓	25			
1	+	33			
2	RETURN	77			
3	CONT	47			
4	−	34			
5	x←( )	67			
6	+	33			
7	3	03			
8	x	36			
9	d	17			
a	+	33			
b	x←( )	67			
c	−	34			
d	e	12			
40	x	36			
1	x←( )	67			
2	−	34			
3	f	15			
4	x	36			
5	1	01			
6	4	04			
7	.	21			
8	7	07			
9	−	34			
a	x←( )	67			
b	+	33			
c	1	01			
d	x	36			
50	x←( )	67			
1	−	34			
2	c	16			
3	x	36			
4	↓	25			
5	x⇄y	30			
6	IF FLAG	43			
7	5	05			
8	c	16			
9	GO TO	44			
a	6	06			
b	0	00			
c	FMT	42			
d	↓	25			

Step	Key	Code	Display x	Display y	Display z
60	RCL	61			
1	+	33			
2	y→( )	40			
3	e	12			
4	a	13			
5	IF x=y	50			
6	6	06			
7	c	16			
8	GO TO	44			
9	+	33			
a	6	06			
b	7	07			
c	GO TO	44			
d	SUB	77			
70	−	34			
1	0	00			
2	0	00			
3	CONT	47			
4	y→( )	40			
5	+	33			
6	8	10			
7	e	12			
8	↑	27			
9	c	16			
a	−	34			
b	x⇄y	30			
c	↑	27			
d	↑	27			

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
80	x	36				0						0					
1	x←()	67				1						1					
2	+	33				2						2					
3	3	03				3						3					
4	x	36				4						4					
5	2	02				5						5					
6	÷	35				6						6					
7	ROLL ↑	22				7						7					
8	x⇄y	30				8						8					
9	d	17				9						9					
a	x	36				a						a					
b	↓	25				b						b					
c	+	33				c						c					
d	x←()	67				d						d					
90	+	33				0						0					
1	0	00				1						1					
2	x	36				2						2					
3	x←()	67				3						3					
4	+	33				4						4					
5	9	11				5						5					
6	+	33				6						6					
7	y←()	40				7						7					
8	+	33				8						8					
9	9	11				9						9					
a	GO TO	44				a						a					
b	+	33				b						b					
c	4	04				c						c					
d	2	02				d						d					
a0	END					0											
1						1											
2						2											
3						3											
4						4											
5						5											
6						6											
7						7											
8						8											
9						9											
a						a											
b						b											
c						c											
d						d											

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

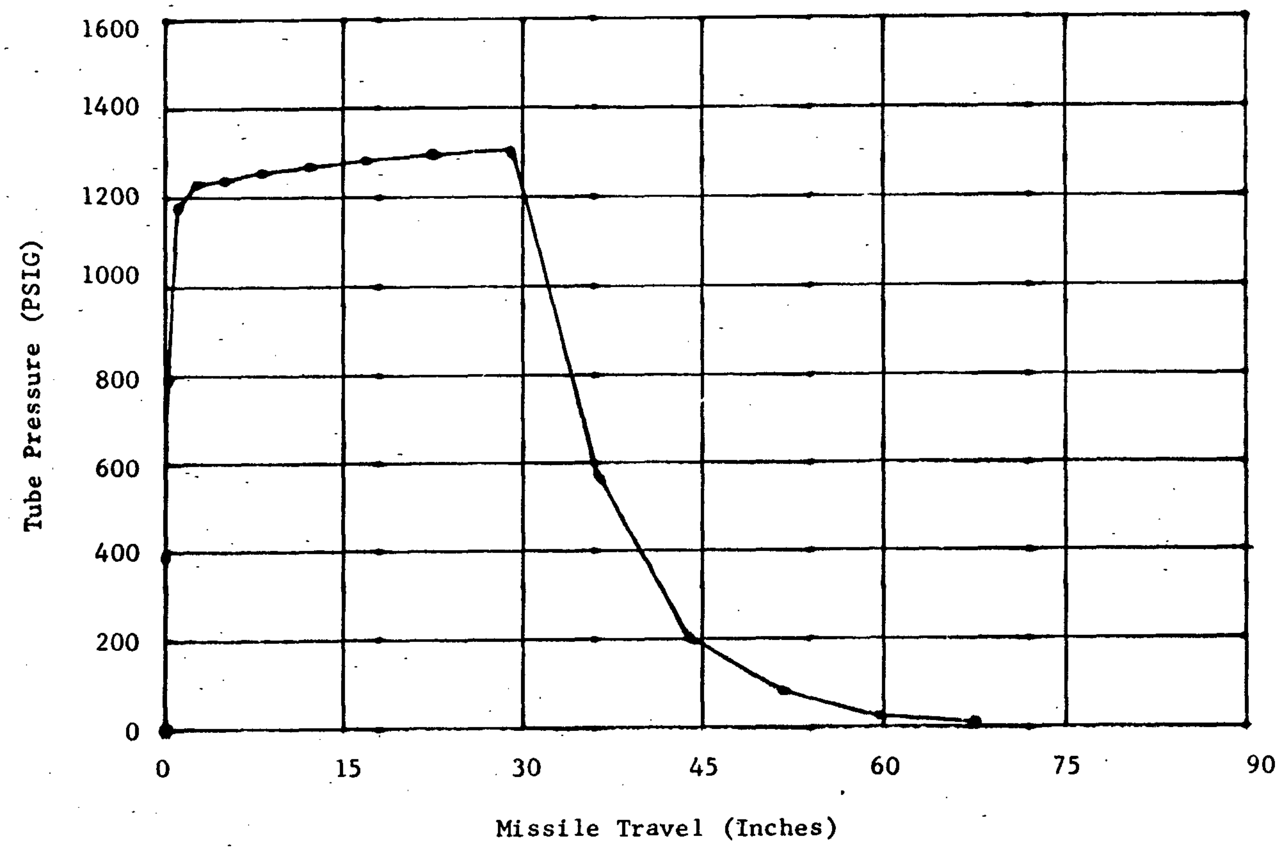

Figure 3-1 . Internal Tube Pressure at Nozzle Exit Versus Missile Travel

3.2 Recoil Prediction

The recoil force predictions are based on the following considerations: missile shoe frictional forces, gas friction forces on the walls of the launch tube, gas impingement on the internal step for a stepped telescoping launcher and gas impingement on the forward face of the tube at missile exit. These forces all contribute to a total force aft (recoil) during a missile firing. Any internal protrusion other than a step would also have to be accounted for in a recoil estimate.

The launch simulation program described in Section IV can be used to obtain the force-time histories of the shoe friction forces and the time at which the exhaust gas would begin to impinge on the step or any other internal protrusion whose location is known. For these times, the nozzle exit stagnation pressure can be determined and this, multiplied by the exposed area on which it acted would give the force. The time at which the missile exits the tube, thus giving exhaust impingement forces on the tube face, can also be found.

A good estimate of the recoil-time history can be obtained by plotting all the separate force-time histories on graph paper and summing to obtain the total force-time history. An example of the result of this process is shown in Figure 3-2 for a stepped telescoping tube.

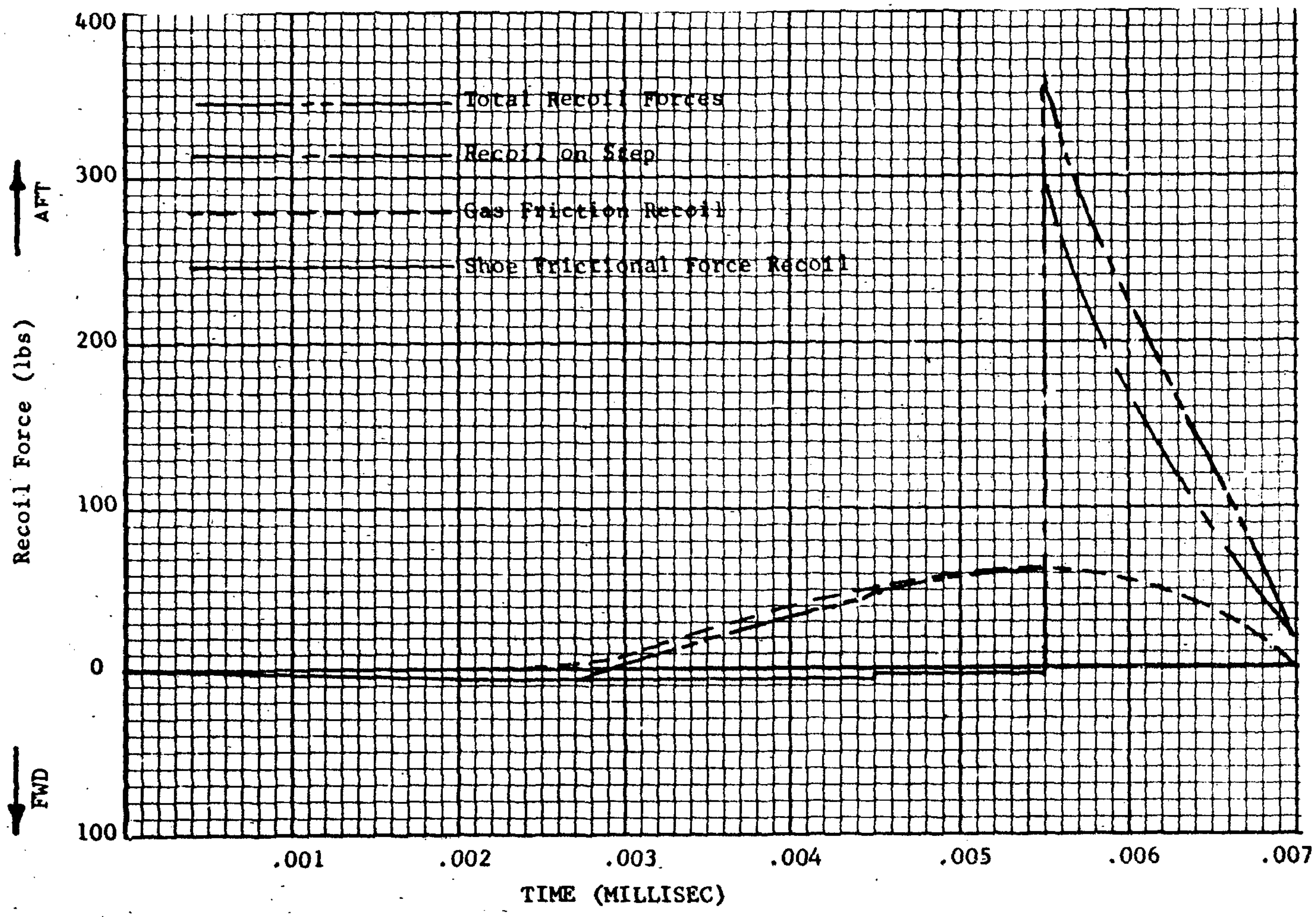

Figure 3-2. Estimation Method for Recoil Forces

Section IV. LAUNCHER SIMULATION

4.1 Introduction

A computer simulation program has been written which simulates launcher performance in the pitch plane. The program is capable of simulating both smooth-bore and stepped telescoping launchers. It has provisions for utilizing a recoil force-time history as an input and for studying the effects of thrust misalignment and center of gravity offset. Figure 4-1 is a representation of a missile and launcher showing the forces accounted for in the simulation program and the dimensional data required.

The basic assumption for the simulation model is that the gross motions of the system are due to the nonrigid support characteristics of a man. The man has been replaced, therefore, by a spring and a damper. Four firing positions were chosen as being readily simulated for various configurations. These positions are depicted in Figure 4-2. In each position a point which appears to have the least translational motion has been chosen as a virtual trunnion. The spring and damper are then converted to torsional equivalents about this point.

This simulation model is intended only to provide gross motions. A representative example of outputs from the program is shown in Figures 4-3, 4-4, 4-5. Results obtained by the use of this program are predictions only and have not been verified by test data. No plans have been made for verification tests at the present time.

4.2 Symbol Definitions

T_1 - T_5 : Time values associated with the missile thrust-time curve.

τ_1 - τ_4 : Thrust values associated with the missile thrust-time curve.

F_c : Coefficient of friction for missile shoe friction forces.

D_f : Damping factor for system dashpot.

F_n : Natural frequency of vibration of system.

I_l : Moment of inertia of launcher about trunnion.

I_r : Roll moment of inertia of missile.

I_m : Missile moment of inertia.

I_t : Total system motion of inertia about trunnion.

U_1 - U_3 : Time values associated with blast force buildup (millisec).

F_{61} - F_{62}	:	Force values associated with blast force buildup.
Δt	:	Integration time increment (sec).
R_a	:	Angular location of thrust misalignment vector from zero reference (counterclockwise positive).
R_c	:	Torque necessary to induce spin on the missile.
W_1	:	Weight of missile (lbs).
W_2	:	Weight of launcher (lbs).
EA	:	Launcher elevation angle.
D_1	:	Distance along X-Axis from missile CG to front shoe (Application of F_1) (inches).
D_2	:	Distance along X-Axis from missile CG to rear shoe (Application of F_2) (inches).
D_3	:	Missile CG offset along Y-Axis (inches).
D_4	:	Missile thrust misalignment (inches).
D_5	:	Distance along Y-Axis from missile centerline to outer edge of shoe (inches).
D_6	:	Distance along Y-Axis from launcher tube centerline to trunnion (inches).
D_7	:	Distance along X-Axis from launcher trunnion to Application of F_1 (inches).
D_8	:	Distance along X-Axis from launcher trunnion to Application of F_2 (inches).
D_9	:	Distance along X-Axis from launcher trunnion to launcher CG (inches).
D_{10}	:	Distance along Y-Axis from launcher trunnion to launcher CG (inches).
D_{11}	:	Overall launch tube length for smooth bore launcher concept; guidance length (inside tube length) for telescoping launcher concept (inches).
D_{12}	:	Outer tube length for telescoping launcher concept (inches).

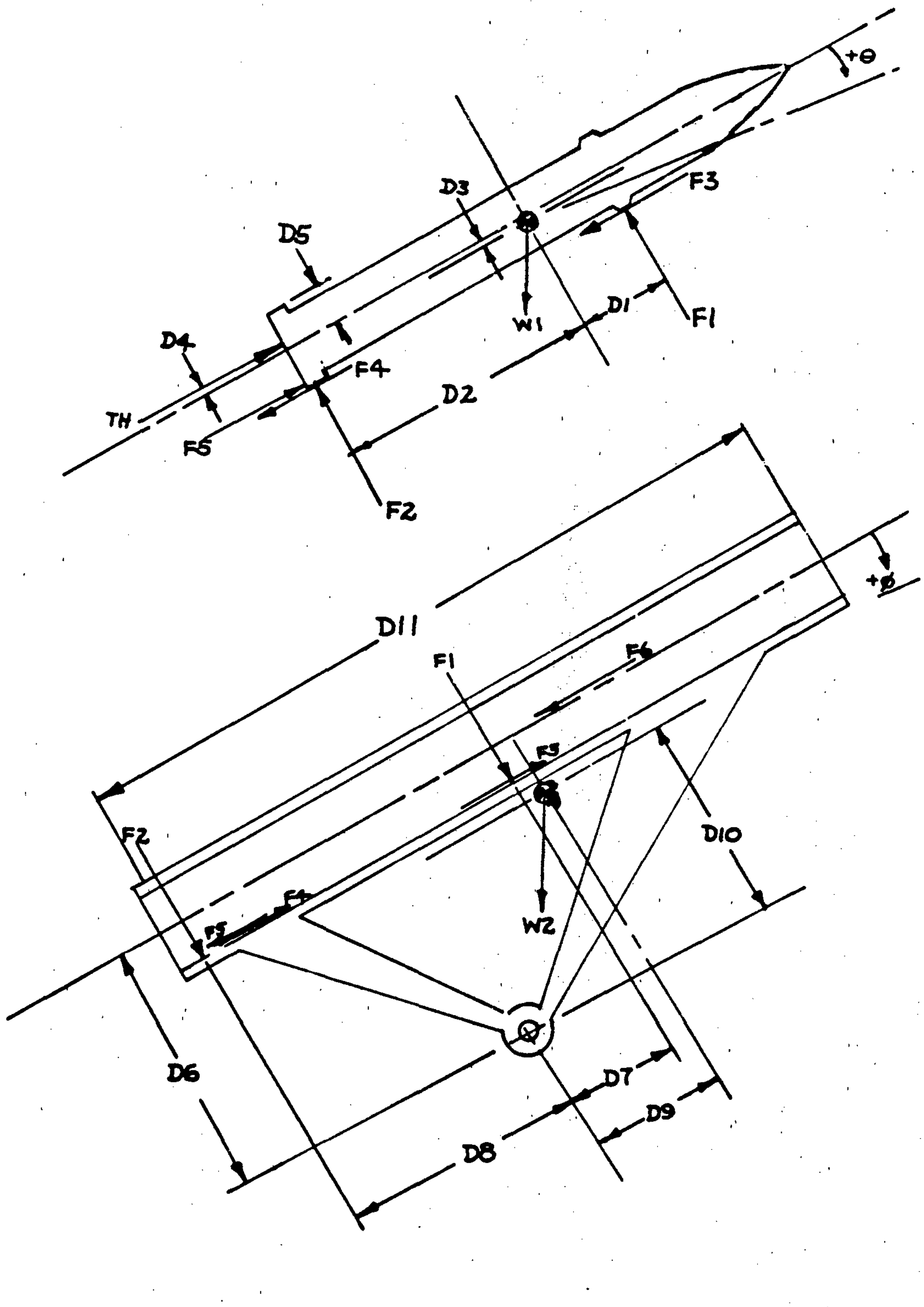

Figure 4-1. Launch Simulation Missile and Launcher Model

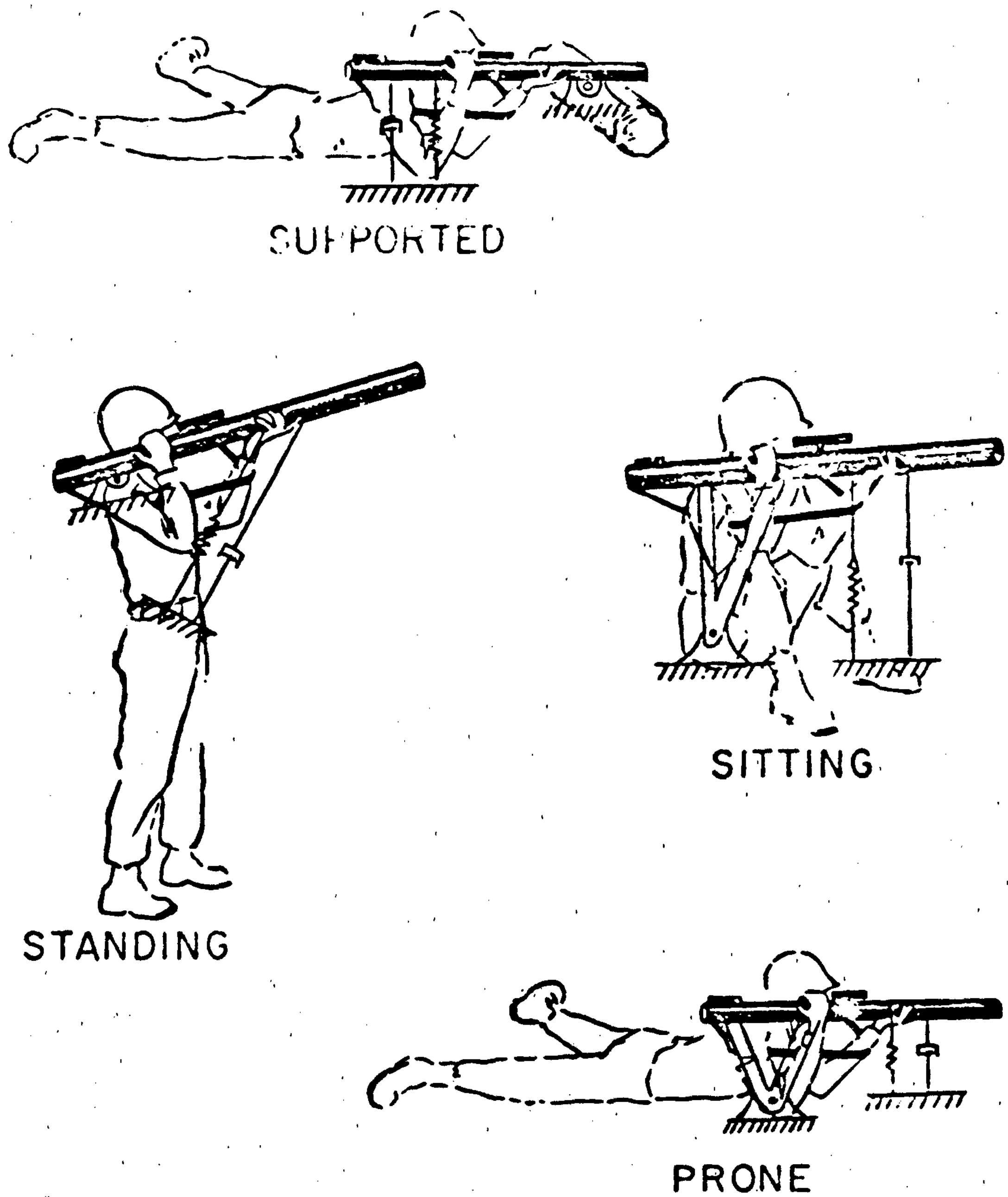

Figure 4-2. Firing Position Models for Launch Simulation

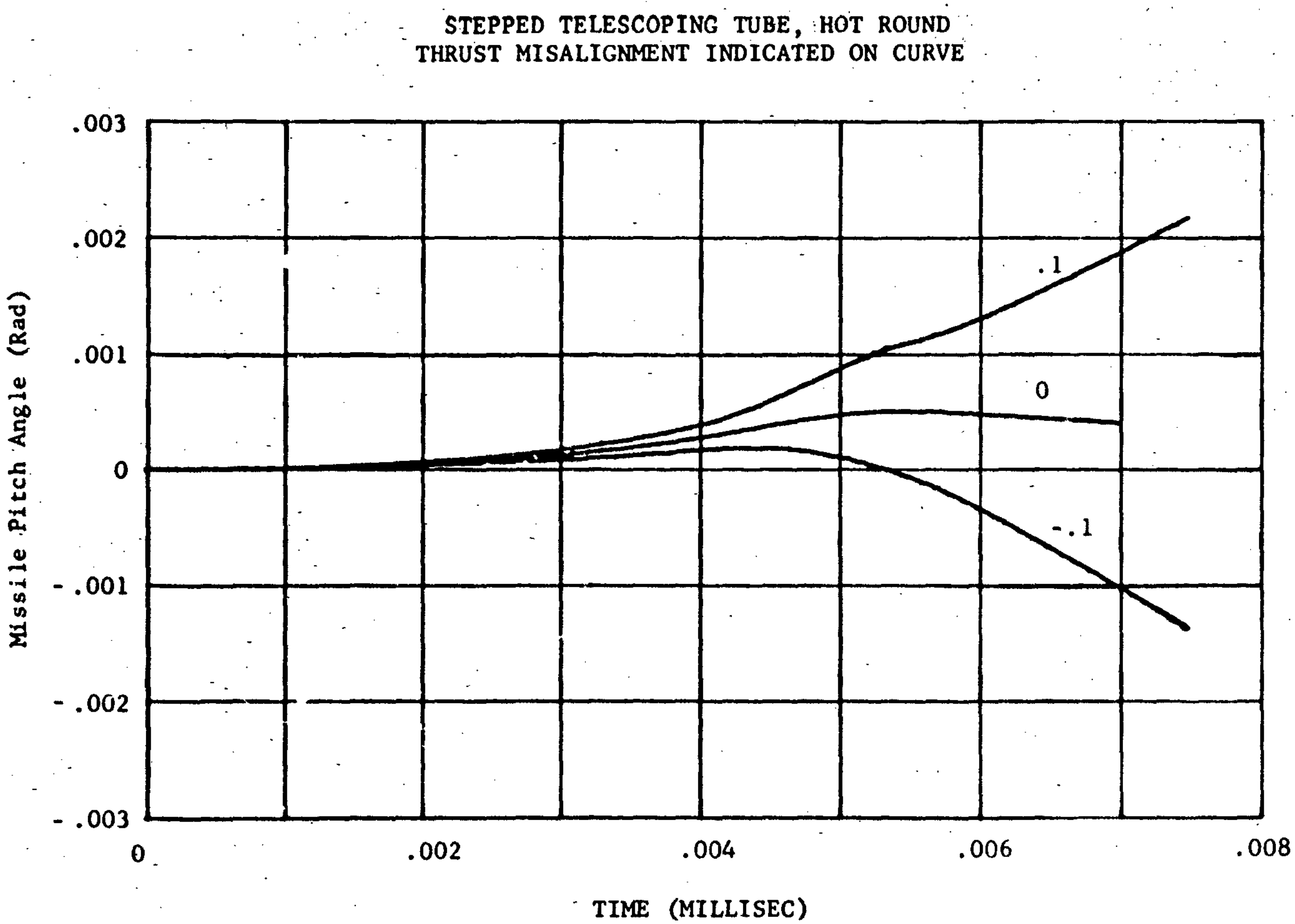

Figure 4-3. Missile Pitch Angle versus Time

STEPPED TELESCOPING TUBE, HOT ROUND
THRUST MISALIGNMENT INDICATED ON PLOT

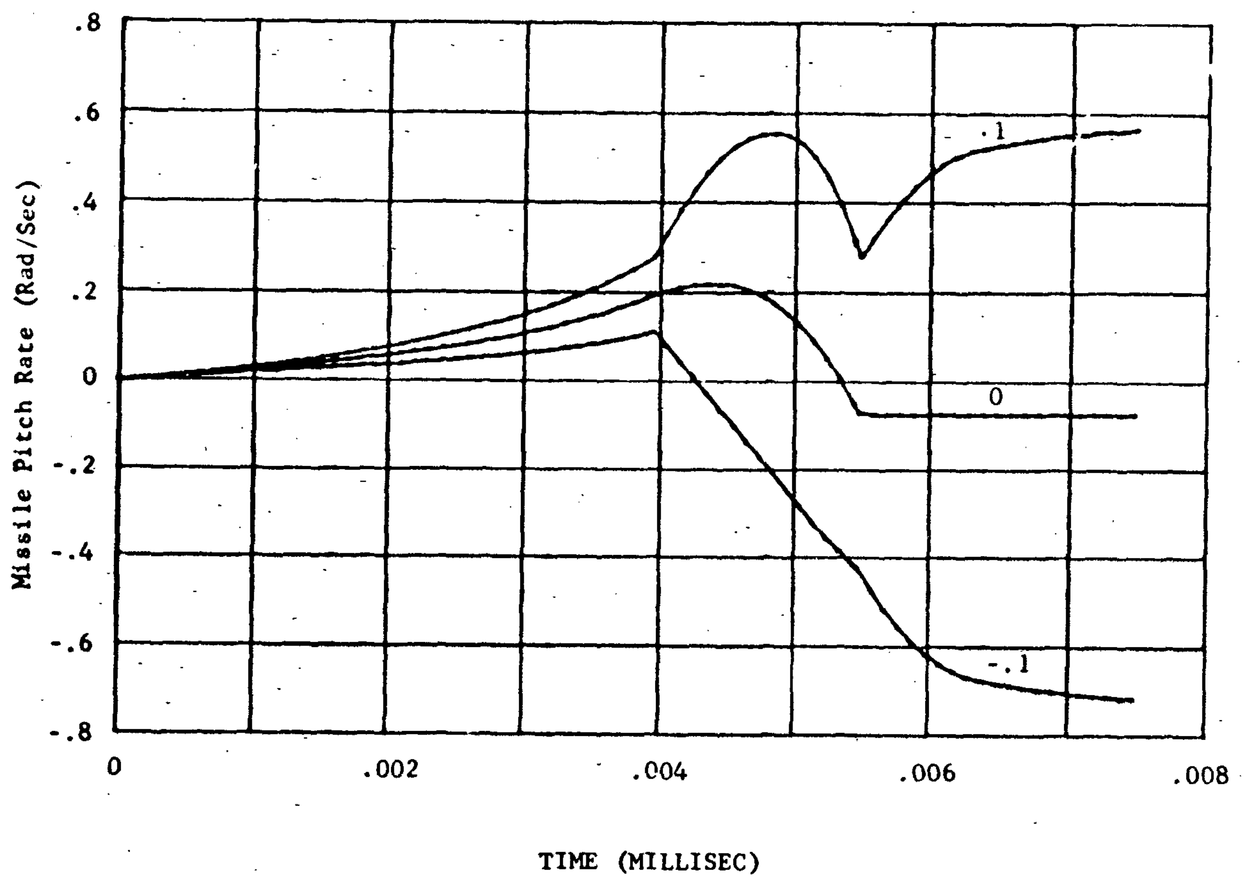

Figure 4-4. Missile Pitch Rate Versus Time

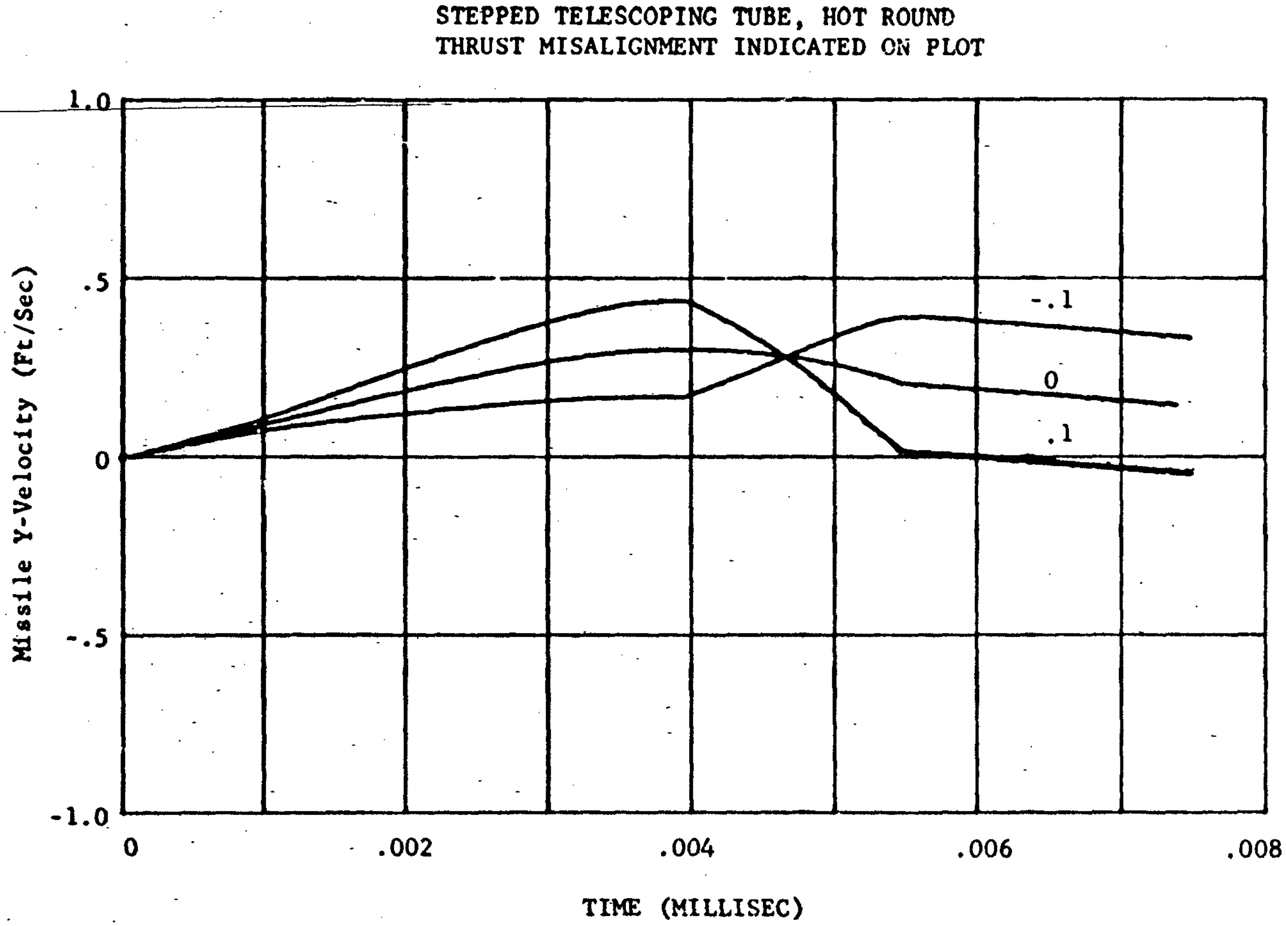

Figure 4-5. Missile Y-Velocity Versus Time

4.3 Launch Simulation Equations

Missile Equations:

$$\Sigma M_{CG} = I_1 \ddot{\theta}$$

$$I_1 \ddot{\theta} = -F_1 D_1 + F_2 D_2 + (F_3 + F_4)(D_5 - D_3) + TH(D_4 + D_3) - F_5(D_5 - D_3)$$

$$\Sigma F_x = M_1 \ddot{x}$$

$$M_1 \ddot{x} = (TH + F_5 - F_3 - F_4 - W_1 \sin EA)\cos\theta + (F_1 + F_2 - W_1 \cos EA)\sin\theta$$

$$\Sigma F_y = M_1 \ddot{Y}$$

$$M_1 \ddot{Y} = (F_1 + F_2 - W_1 \cos EA)\cos\theta - (TH + F_5 - F_3 - F_4 - W_1 \sin EA)\sin\theta$$

Launcher Equations:

$$\Sigma M_T = I_2 \ddot{\psi}$$

$$I_2 \ddot{\psi} = s(\psi_s - \psi) - C\dot{\psi} + F_1(D_7 + x) - F_2(D_8 - x) + (F_3 + F_4)(D_6 - D_5)$$

$$- F_5(D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D - W_2 \sin(EA - \psi) D_{10}$$

Relative Motion:

$$Y = -(D_6 - D_5)(1 - \cos\psi) + (D_8 - x)\sin\psi - (D_5 - D_3)(1 - \cos\theta) - D_2 \sin\theta$$

$$\dot{Y} = -\dot{\psi}(D_6 - D_5)\sin\psi + \dot{\psi} D_8 \cos\psi - x\dot{\psi}\cos\psi - \dot{x}\sin\psi - \dot{\theta}(D_5 - D_3)\sin\theta - \dot{\theta} D_2 \cos\theta$$

$$\ddot{Y} = -(D_6 - D_5)\dot{\psi}^2 \cos\psi - (D_6 - D_5)\ddot{\psi}\sin\psi - D_8 \dot{\psi}^2 \sin\psi + D_8 \ddot{\psi}\cos\psi$$

$$+ x\dot{\psi}^2 \sin\psi - x\ddot{\psi}\cos\psi - 2\dot{x}\dot{\psi}\cos\psi - \ddot{x}\sin\psi - (D_5 - D_3)\dot{\theta}^2 \cos\theta$$

$$- (D_5 - D_3)\ddot{\theta}\sin\theta + D_2 \dot{\theta}^2 \sin\theta - D_2 \ddot{\theta}\cos\theta$$

FOR THE MISSILE :

LET $F_3 = F_1 + FC$
$F_4 = F_2 + FC$

THEN

$$I_1 \ddot{\theta} = -F_1 D_1 + F_2 D_2 + FC(F_1 + F_2)(D_5 - D_3) + TH(D_4 + D_3) - F_5(D_5 - D_3)$$

FROM SMALL ANGLE ASSUMPTION $\cos\theta \approx 1$
$\sin\theta \approx 0$

THEREFORE

$$M_1 \ddot{X} = TH + F_5 - W_1 \sin EA - F_3 - F_4$$
$$= TH + F_5 - W_1 \sin EA - FC(F_1 + F_2)$$

$$M_1 \ddot{Y} = -W_1 \cos EA + F_1 + F_2 - TH \sin\theta$$

$$I_1 \ddot{\theta} = F_1[-D_1 + FC(D_5 - D_3)] + F_2[D_2 + FC(D_5 - D_3)] + TH(D_4 + D_3) - F_5(D_5 - D_3)$$

LET $E_1 = D_1 + FC(D_5 - D_3)$
$E_2 = D_2 + FC(D_5 - D_3)$
$E_3 = D_4 + D_3$
$E_4 = D_5 - D_3$

THEN

$$I_1 \ddot{\theta} = -E_1 F_1 + E_2 F_2 + E_3 TH - E_4 F_5$$

AND

$$F_1 + F_2 = M_1 \ddot{Y} + TH \sin\theta + W_1 \cos EA$$

FOR THE LAUNCHER:

$$I_2 \ddot{\psi} = s(\psi_s - \psi) - c\dot{\psi} + F_1 D_7 - F_2 D_8 + (F_1 + F_2)x + F_3 \phi_1 + F_4 \phi_2$$

$$- F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$$

WHERE IF

F_1 IS $+$, $\phi_1 = D_6 - D_5$

F_1 IS $-$, $\phi_1 = -(D_6 - D_5)$

F_2 IS $+$, $\phi_2 = D_6 - D_5$

F_2 IS $-$, $\phi_2 = -(D_6 - D_5)$

$$I_2 \ddot{\psi} = s(\psi_s - \psi) - c\dot{\psi} + F_1 D_7 - F_2 D_8 + (F_1 + F_2)x + F_1 FC \phi_1 + F_2 FC \phi_2$$

$$- F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$$

$$I_2 \ddot{\psi} = s(\psi_s - \psi) - c\dot{\psi} + (D_7 + FC\phi_1 + x)F_1 - (D_8 - FC\phi_2 - x)F_2$$

$$- F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$$

LET

$X_1 = D_7 + FC\phi_1 + x$

$X_2 = D_8 - FC\phi_2 - x$

$Z_1 = -F_5 (D_6 - D_5) - F_6 D_6 + W_2 \cos(EA - \psi) D_9 - W_2 \sin(EA - \psi) D_{10}$

THEREFORE

$$I_2 \ddot{\psi} = s(\psi_s - \psi) - c\dot{\psi} + X_1 F_1 - {}_2F_2 + Z_1$$

FROM EQUATIONS FOR RELATIVE MOTION, GROUPING TERMS AND LETTING

$$Z_2 = -(D_6 - D_5)\dot{\psi}^2 \cos\psi - D_8 \dot{\psi}^2 \sin\psi + x\dot{\psi}^2 \sin\psi - 2\dot{x}\dot{\psi}\cos\psi$$

$$- (D_5 - D_3)\dot{\theta}^2 \cos\theta + D_2 \dot{\theta}^2 \sin\theta$$

$$X_3 = D_8 \cos\psi - (D_6 - D_5)\sin\psi - x\cos\psi$$

$$X_4 = (D_5 - D_3)\sin\theta + D_2 \cos\theta$$

WE HAVE

$$\ddot{Y} = X_3 \ddot{\psi} - X_4 \ddot{\theta} - \ddot{x}\sin\psi + Z_2$$

SINCE

$$F_1 + F_2 = M_1 \ddot{Y} + TH \sin\theta + W_1 \cos EA$$

$$= M_1 [X_3 \ddot{\psi} - X_4 \ddot{\theta} - \ddot{x}\sin\psi + Z_2] + TH \sin\theta + W_1 \cos EA$$

LETTING

$$Z_3 = -M_1 \ddot{x} \sin\psi + M_1 Z_2 + TH \sin\theta + W_1 \cos EA$$

GIVES

$$F_1 + F_2 = M_1 X_3 \ddot{\psi} - M_1 X_4 \ddot{\theta} + Z_3$$

SOLVING FOR F_1:

$$I_1\ddot{\theta} = -E_1F_1 + E_2F_2 + E_3TH - E_4F_5$$

$$E_1F_1 - E_2F_2 = -I_1\ddot{\theta} + E_3TH - E_4F_5$$
$$E_2F_1 + E_2F_2 = E_2M_1x_3\ddot{\psi} - E_2M_1x_4\ddot{\theta} + E_2z_3$$

$$(E_1+E_2)F_1 = E_2M_1x_3\ddot{\psi} - (E_2M_1x_4 + I_1)\ddot{\theta} + E_2z_3 + E_3TH - E_4F_5$$

$$F_1 = \frac{E_2M_1}{E_1+E_2}x_3\ddot{\psi} - \left[\frac{E_2M_1}{E_1+E_2}x_4 + \frac{I_1}{E_1+E_2}\right]\ddot{\theta} + \frac{E_2}{E_1+E_2}z_3 + \frac{E_3}{E_1+E_2}TH - \frac{E_4}{E_1+E_2}F_5$$

LETTING

$$E_5 = \frac{E_2M_1}{E_1+E_2} \qquad E_7 = \frac{E_2}{E_1+E_2} \qquad E_9 = \frac{E_4}{E_1+E_2}$$

$$E_6 = \frac{I_1}{E_1+E_2} \qquad E_8 = \frac{E_3}{E_1+E_2}$$

$$F_1 = E_5x_3\ddot{\psi} - (E_5x_4 + E_6)\ddot{\theta} + E_7z_3 + E_8TH - E_9F_5$$

SOLVING FOR F_2:

$$F_2 = -E_{10}x_3\ddot{\psi} + (E_{10}x_4 + E_6)\ddot{\theta} + E_{11}z_3 - E_8TH + E_9F_5$$

WHERE $E_{10} = E_5 - M_1$
$E_{11} = 1 - E_7$

THEN, WITH

$$x_5 = E_5x_4 + E_6$$
$$x_6 = E_{10}x_4 + E_6$$
$$z_4 = E_7z_3 + E_8TH - E_9F_5$$
$$z_5 = E_{11}z_3 - E_8TH + E_9F_5$$

WE HAVE

$$F_1 = E_5 X_3 \ddot{\psi} - X_5 \ddot{\theta} + Z_4$$
$$F_2 = -E_{10} X_3 \ddot{\psi} + X_6 \ddot{\theta} + Z_5$$

THERE ARE THREE CASES TO BE CONSIDERED

CASE I : MISSILE IN INNER TUBE $(\ddot{\psi} = \ddot{\theta})$
CASE II : FRONT SHOES DROP OFF $(F_1 = 0)$
CASE III: REAR SHOES DROP OFF $(F_1 = F_2 = 0)$

CASE I : $\ddot{\psi} = \ddot{\theta}$

$$I_2 \ddot{\psi} = S(\psi_f - \psi) - C\dot{\psi} + X_1 \left[E_5 X_3 \ddot{\psi} - X_5 \ddot{\theta} + Z_4\right] - X_2 \left[-E_{10} X_3 \ddot{\psi} + X_6 \ddot{\theta} + Z_5\right] + Z_1$$

$$\ddot{\psi} = \left[S(\psi_f - \psi) - C\dot{\psi} + X_1 Z_4 - X_2 Z_5 + Z_1\right] / \left[I_2 - E_5 X_1 X_3 + X_1 X_5 - E_{10} X_2 X_3 + X_2 X_6\right]$$

$$\ddot{Y} = (X_3 - X_4)\ddot{\psi} - \ddot{X} \sin\psi + Z_2$$

$$F_1 = E_5 X_3 \ddot{\psi} - X_5 \ddot{\theta} + Z_4$$

$$F_2 = -E_{10} X_3 \ddot{\psi} + X_6 \ddot{\theta} + Z_5$$

CASE II: $F_1 = 0$

$$I_1\ddot{\theta} = E_2F_2 + E_3TH$$

$$F_2 = M_1X_3\ddot{\psi} - M_1X_4\ddot{\theta} + Z_3$$

$$\therefore\quad I_1\ddot{\theta} = E_2M_1X_3\ddot{\psi} - E_2M_1X_4\ddot{\theta} + E_2Z_3 + E_3TH$$

$$\ddot{\theta}\left(I_1 + E_2M_1X_4\right) = E_2M_1X_3\ddot{\psi} + E_2Z_3 + E_3TH$$

LET

$$X_9 = I_1 + E_2M_1X_4$$
$$X_{10} = E_2M_1X_3$$
$$Z_7 = E_2Z_3 + E_3TH$$

$$\therefore\quad X_9\ddot{\theta} = X_{10}\ddot{\psi} + Z_7$$

$$I_2\ddot{\psi} = s(\psi_f - \psi) - c\dot{\psi} - X_2F_2 + Z_1$$

$$= s(\psi_f - \psi) - c\dot{\psi} + Z_1 - X_2M_1X_3\ddot{\psi} + X_2M_1X_4\ddot{\theta} - X_2Z_3$$

$$\ddot{\psi}\left(I_2 + X_2X_3M_1\right) = s(\psi_f - \psi) - c\dot{\psi} + Z_1 + X_2X_4M_1\ddot{\theta} - X_2Z_3$$

LET

$$X_7 = I_2 + X_2X_3M_1$$
$$X_8 = M_1X_2X_4$$
$$Z_6 = Z_1 - X_2Z_3$$

$$\therefore\quad X_7\ddot{\psi} = s(\psi_f - \psi) - c\dot{\psi} + X_8\ddot{\theta} + Z_6$$

SOLVING FOR $\ddot{\theta}$ AND $\ddot{\psi}$:

$$\ddot{\theta} = \left[s(\psi_f - \psi)X_{10} - cX_{10}\dot{\psi} + X_{10}Z_6 + X_7Z_7\right] / \left(X_7X_9 - X_8X_{10}\right)$$

$$\ddot{\psi} = \left[s(\psi_f - \psi)X_9 - cX_9\dot{\psi} + X_8Z_7 + X_9Z_6\right] / \left(X_7X_9 - X_8X_{10}\right)$$

$$F_2 = M_1 x_3 \ddot{\psi} - M_1 x_4 \ddot{\theta} + z_3$$

$$\ddot{Y} = x_3 \ddot{\psi} - x_4 \ddot{\theta} - \ddot{X} \sin \psi + z_2$$

CASE III : $F_1 = F_2 = 0$

$$I_1 \ddot{\theta} = E_3 TH$$

$$\ddot{\theta} = \frac{E_3}{I_1} TH$$

$$I_2 \ddot{\psi} = s(\psi_f - \psi) - c\dot{\psi} + z_1$$

$$\ddot{\psi} = \frac{1}{I_2}\left[s(\psi_f - \psi) - c\dot{\psi} + z_1\right]$$

$$\ddot{Y} = x_3 \ddot{\psi} - x_4 \ddot{\theta} - \ddot{X} \sin \psi + z_2$$

4.4 Description and Program

This launcher simulation program has been written for the Hewlett-Packard 9100B with Extended Memory and Card Reader Units. As such, it is composed of a number of programs which perform specific calculations. Since the calculations involved were so lengthy the basic program had to be broken into two different parts.

Part I consists of programs P_o, P_1, P_2 and P_3. These are the input and initialization parts of the program. The input data controlled by these programs is entered into the machine via marked Data Cards. After data is input and initial conditions are set, Part II of the program is entered. Part II consists of programs P_{20}, P_{25}, P_{26}, P_{30}, P_{35}, P_{36}, P_{37}, P_{38}, P_{39}, P_{40}, P_{41}, P_{42}, P_{10}, P_{11} and P_{12}. These programs perform the integrations of the equations and calculate all output data. Program P_{20} calculates thrust values; P_{25} calculates missile roll; P_{26} calculates motions along X-Axis; P_{30} calculates friction blast; P_{35}, P_{36}, P_{37}, P_{38}, P_{39} calculate values for the X_1 -X_{10}, Z_1 - Z_6, and E_1 - E_{11} terms; P_{40}, P_{41} and P_{42} Case I programs solve the equations for the Case I conditions, P_{40}, P_{41}, and P_{42} Case II programs handle the Case II equations and P_{40}, P_{41}, and P_{42} Case III programs handle the Case III equations; P_{10} is the plot program; P_{11} the time increment program and P_{12} the time comparison program.

When the Case II conditions are reached the program will halt execution and the programs for this condition must be entered. The same procedure occurs for Case III conditions.

For plots, when entering P_{10} follow this procedure: (1) Enter P_{10} in 9100 B Memory (2) Press STOP, END (3) Place switch on PROGRAM mode (4) Press STEP PROGRAM (5) Enter three-digit memory location of value to be plotted versus time and (6) Enter P_{10} in extended memory. This must be performed each time a different plot variable is desired.

Date ____________ Page 1 of 1

TABLE 4-1 LAUNCH SIMULATION MEMORY MAP

0		50		100		150		200	$\ddot{y}$
1		51		101		151		201	SF_x
2		52		102	P_{38}	152		202	$\dot{r}$
3		53		103		153	P_{10}	203	$\ddot{r}$
4		54		104		154		204	τ
5		55		105		155		205	F_1
6	P_0 P_{20}	56		106		156	P_{11}	206	F_2
7		57		107		157		207	F_E
8		58		108		158		208	F_L
9		59		109		159	P_{12}	209	R_c
10		60		110		160		210	r_{ou}
11		61	P_{35}	111		161		211	F_{L2}
12		62		112		162	I_T	212	F_{L1}
13		63		113		163	R_a	213	U_3
14		64		114	P_{39}	164	Z_7	214	U_2
15		65		115		165	Z_6	215	U_1
16		66		116		166	Z_5	216	ς
17		67		117		167	X_6	217	t_p
18	P_1	68		118		168	X_{11}	218	Δt
19		69		119		169	X_{10}	219	I_ℓ
20	P_{25}	70		120		170	X_9	220	I_r
21		71		121		171	X_8	221	I_m
22		72		122		172	X_7	222	F_c
23		73		123		173	Z_4	223	D_F
24		74	P_{36}	124		174	X_5	224	F_N
25		75		125		175	Z_3	225	W_2
26		76		126		176	Z_2	226	W_1
27		77		127	P_{40}	177	X_4	227	τ_4
28		78		128		178	X_3	228	τ_3
29		79		129		179	Z_1	229	τ_2
30		80		130		180	X_2	230	τ_1
31	P_2	81		131		181	X_1	231	T_5
32	P_{26}	82		132		182	V_2	232	T_4
33		83		133		183	V_r	233	T_3
34		84		134		184	BC	234	T_2
35		85		135		185	TD	235	T_1
36		86		136		186	PF	236	D_{12}
37		87	P_{37}	137	P_{41}	187	SF_y	237	D_{11}
38		88		138		188	t	238	D_{10}
39		89		139		189	θ	239	D_9
40		90		140		190	$\dot{\theta}$	240	D_8
41		91		141		191	$\ddot{\theta}$	241	D_7
42		92		142		192	ϕ	242	D_6
43		93		143		193	$\dot{\phi}$	243	D_5
44		94		144		194	$\ddot{\phi}$	244	D_4
45		95		145	P_{42}	195	x	245	D_3
46	P_3	96		146		196	$\dot{x}$	246	D_2
47	P_{30}	97		147		197	$\ddot{x}$	247	D_1
48		98		148		198	y		
49		99		149		199	$\dot{y}$		

Title LAUNCH SIMULATION P_o PAGE 1 OF 2.

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
01	1	01			
02	STOP	41	D_3	D_2	D_1
03	PAUSE	57			
04	x→()	23			
05	f	15			
06	2	02			
07	4	04			
08	6	06			
09	FMT	42			
0a	y→()	40			
0b	↓	25			
0c	2	02			
0d	4	04			
10	7	07			
11	FMT	42			
12	y→()	40			
13	f	15			
14	↑	27			
15	2	02			
16	4	04			
17	5	05			
18	FMT	42			
19	y→()	40			
1a	CLEAR	20			
1b	2	02			
1c	STOP	41	D_6	D_5	D_4
1d	PAUSE	57			
20	x→()	23			
21	f	15			
22	2	02			
23	4	04			
24	3	03			
25	FMT	42			
26	y→()	40			
27	↓	25			
28	2	02			
29	4	04			
2a	4	04			
2b	FMT	42			
2c	y→()	40			
2d	f	15			

Step	Key	Code	Display x	Display y	Display z
30	↑	27			
31	2	02			
32	4	04			
33	2	02			
34	FMT	42			
35	y→()	40			
36	CLEAR	20			
37	3	03			
38	STOP	41	D_9	D_8	D_7
39	PAUSE	57			
3a	x→()	23			
3b	f	15			
3c	2	02			
3d	4	04			
40	0	00			
41	FMT	42			
42	y→()	40			
43	↓	25			
44	2	02			
45	4	04			
46	1	01			
47	FMT	42			
48	y→()	40			
49	f	15			
4a	↑	27			
4b	2	02			
4c	3	03			
4d	9	11			
50	FMT	42			
51	y→()	40			
52	CLEAR	20			
53	4	04			
54	STOP	41	D_{12}	D_{11}	D_{10}
55	PAUSE	57			
56	x→()	23			
57	f	15			
58	2	02			
59	3	03			
5a	7	07			
5b	FMT	42			
5c	y→()	40			
5d	↓	25			

Step	Key	Code	Display x	Display y	Display z
60	2	02			
61	3	03			
62	8	10			
63	FMT	42			
64	y→()	40			
65	f	15			
66	↑	27			
67	2	02			
68	3	03			
69	6	06			
6a	FMT	42			
6b	y→()	40			
6c	CLEAR	20			
6d	5	05			
70	STOP	41	T_3	T_2	T_1
71	PAUSE	57			
72	x→()	23			
73	f	15			
74	2	02			
75	3	03			
76	4	04			
77	FMT	42			
78	y→()	40			
79	↓	25			
7a	2	02			
7b	3	03			
7c	5	05			
7d	FMT	42			

Register	Storage
f	
e	
d	
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b	
a	
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0	

Title LAUNCH SIMULATION P_0 PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
80	y→()	40			
1	f	15			
2	↑	27			
3	2	02			
4	3	03			
5	3	03			
6	FMT	42			
7	y→()	40			
8	CLEAR	20			
9	6	06			
a	STOP	41	τ_1	T_5	T_4
b	PAUSE	57			
c	x→()	23			
d	f	15			
90	2	02			
1	3	03			
2	1	01			
3	FMT	42			
4	y→()	40			
5	↓	25			
6	2	02			
7	3	03			
8	2	02			
9	FMT	42			
a	y→()	40			
b	f	15			
c	↑	27			
d	2	02			
a0	3	03			
1	0	00			
2	FMT	42			
3	y→()	40			
4	CLEAR	20			
5	7	07			
6	STOP	41	τ_4	τ_3	τ_2
7	PAUSE	57			
8	x→()	23			
9	f	15			
a	2	02			
b	2	02			
c	8	10			
d	FMT	42			
b0	y→()	40			
1	↓	25			
2	2	02			
3	2	02			
4	9	11			
5	FMT	42			
6	y→()	40			
7	f	15			
8	↑	27			
9	2	02			
a	2	02			
b	7	07			
c	FMT	42			
d	y→()	40			
c0	CLEAR	20			
1	8	10			
2	STOP	41			
3	PAUSE	57			
4	x→()	23			
5	f	15			
6	2	02			
7	2	02			
8	5	05			
9	FMT	42			
a	y→()	40			
b	↓	25			
c	2	02			
d	2	02			
d0	6	06			
1	FMT	42			
2	y→()	40			
3	f	15			
4	↑	27			
5	2	02			
6	1	01			
7	6	06			
8	FMT	42			
9	y→()	40			
a	1	01			
b	FMT	42			
c	GO TO	44			
d	END	46			

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P_1

Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20			
1	9	11			
2	STOP	41	F_c	D_F	F_N
3	PAUSE	57			
4	x→()	23			
5	f	15			
6	2	02			
7	2	02			
8	3	03			
9	FMT	42			
a	y→()	40			
b	↓	25			
c	2	02			
d	2	02			
10	4	04			
1	FMT	42			
2	y→()	40			
3	f	15			
4	↑	27			
5	2	02			
6	2	02			
7	2	02			
8	FMT	42			
9	y→()	40			
a	CLEAR	20			
b	1	01			
c	0	00			
d	STOP	41	I_ℓ	I_r	I_m
20	PAUSE	57			
1	x→()	23			
2	f	15			
3	2	02			
4	2	02			
5	0	00			
6	FMT	42			
7	y→()	40			
8	↓	25			
9	2	02			
a	2	02			
b	1	01			
c	FMT	42			
d	y→()	40			

Step	Key	Code	Display x	Display y	Display z
30	f	15			
1	↑	27			
2	2	02			
3	1	01			
4	9	11			
5	FMT	42			
6	y→()	40			
7	CLEAR	20			
8	1	01			
9	1	01			
a	STOP	41	U_3	U_2	U_1
b	PAUSE	57			
c	x→()	23			
d	f	15			
40	2	02			
1	1	01			
2	4	04			
3	FMT	42			
4	y→()	40			
5	↓	25			
6	2	02			
7	1	01			
8	5	05			
9	FMT	42			
a	y→()	40			
b	f	15			
c	↑	27			
d	2	02			
50	1	01			
1	3	03			
2	FMT	48			
3	y→()	40			
4	CLEAR	20			
5	1	01			
6	2	02			
7	STOP	41	t_P	F_{o2}	F_{o1}
8	PAUSE	57			
9	x→()	23			
a	f	15			
b	2	02			
c	1	01			
d	1	01			

Step	Key	Code	Display x	Display y	Display z
60	FMT	42			
1	y→()	40			
2	↓	25			
3	2	02			
4	1	01			
5	2	02			
6	FMT	42			
7	y→()	40			
8	f	15			
9	↑	27			
a	2	02			
b	1	01			
c	7	07			
d	FMT	42			
70	y→()	40			
1	CLEAR	20			
2	1	01			
3	3	03			
4	STOP	41	Δt	R_c	R_a
5	PAUSE	57			
6	x→()	23			
7	f	15			
8	2	02			
9	0	00			
a	9	11			
b	FMT	42			
c	y→()	40			
d	↓	25			

Storage	
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b	
a	
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5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P1 PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
8 0	1	01				0						0					
1	6	06				1						1					
2	3	03				2						2					
3	FMT	42				3						3					
4	y→( )	40				4						4					
5	f	15				5						5					
6	↑	27				6						6					
7	2	02				7						7					
8	1	01				8						8					
9	8	10				9						9					
a	FMT	42				a						a					
b	y→( )	40				b						b					
c	CLEAR	20				c						c					
d	1	01				d						d					
9 0	4	04				0						0					
1	STOP	41				1						1					
2	PAUSE	57				2						2					
3	x→( )	23				3						3					
4	f	15				4						4					
5	1	01				5						5					
6	8	10				6						6					
7	7	07				7						7					
8	FMT	42				8						8					
9	y→( )	40				9						9					
a	↓	25				a						a					
b	1	01				b						b					
c	6	06				c						c					
d	2	02				d						d					
a 0	FMT	42				0											
1	y→( )	40				1											
2	f	15				2											
3	↑	27				3											
4	2	02				4											
5	0	00				5											
6	1	01				6											
7	FMT	42				7											
8	y→( )	40				8											
9	2	02				9											
a	FMT	42				a											
b	GO TO	44				b											
c	END	46				c											
d						d											

Storage

f	
e	
d	
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8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P2 PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	2	02			
02	4	04			
03	3	03			
04	FMT	42			
05	π	56			
06	↑	27			
07	2	02			
08	4	04			
09	5	05			
0a	FMT	42			
0b	π	56			
0c	−	34			
0d	2	02			
10	1	01			
11	6	06			
12	FMT	42			
13	π	56			
14	↑	27			
15	ROLL ↓	31			
16	SIN X	70			
17	x	36			
18	ROLL ↑	22			
19	COS X	73			
1a	x⇄y	30			
1b	2	02			
1c	4	04			
1d	6	06			
20	FMT	42			
21	π	56			
22	x	36			
23	ROLL ↓	31			
24	x⇄y	30			
25	−	34			
26	2	02			
27	2	02			
28	6	06			
29	FMT	42			
2a	π	56			
2b	x	36			
2c	2	02			
2d	4	04			
30	7	07			
31	FMT	42			
32	π	56			
33	ROLL ↑	22			
34	+	33			
35	↓	25			
36	÷	35			
37	2	02			
38	0	00			
39	5	05			
3a	FMT	42			
3b	y→()	40			
3c	2	02			
3d	1	01			
40	6	06			
41	FMT	42			
42	π	56			
43	COS X	73			
44	↑	27			
45	2	02			
46	2	02			
47	6	06			
48	FMT	42			
49	π	56			
4a	x	36			
4b	↓	25			
4c	x⇄y	30			
4d	−	34			
50	2	02			
51	0	00			
52	6	06			
53	FMT	42			
54	y→()	40			
55	2	02			
56	1	01			
57	6	06			
58	FMT	42			
59	π	56			
5a	SIN X	70			
5b	↑	27			
5c	2	02			
5d	2	02			
60	6	06			
61	FMT	42			
62	π	56			
63	x	36			
64	2	02			
65	0	00			
66	5	05			
67	FMT	42			
68	π	56			
69	↑	27			
6a	|y|	55			
6b	2	02			
6c	0	00			
6d	6	06			
70	FMT	42			
71	π	56			
72	x⇄y	30			
73	|y|	55			
74	+	33			
75	2	02			
76	2	02			
77	2	02			
78	FMT	42			
79	π	56			
7a	x	36			
7b	↓	25			
7c	+	33			
7d	2	02			

Storage

Register	Storage
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P2

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
8 0	0	00				b 0	9	11				0					
1	7	07				1	7	07				1					
2	FMT	42				2	FMT	42				2					
3	y→()	40				3	y→()	40				3					
4	0	00				4	1	01				4					
5	↑	27				5	9	11				5					
6	2	02				6	6	06				6					
7	0	00				7	FMT	42				7					
8	8	10				8	y→()	40				8					
9	FMT	42				9	1	01				9					
a	y→()	40				a	9	11				a					
b	2	02				b	5	05				b					
c	0	00				c	FMT	42				c					
d	4	04				d	y→()	40				d					
9 0	FMT	42				c 0	1	01				0					
1	y→()	40				1	9	11				1					
2	2	02				2	4	04				2					
3	0	00				3	FMT	42				3					
4	3	03				4	y→()	40				4					
5	FMT	42				5	1	01				5					
6	y→()	40				6	9	11				6					
7	2	02				7	3	03				7					
8	0	00				8	FMT	42				8					
9	2	02				9	y→()	40				9					
a	FMT	42				a	1	01				a					
b	y→()	40				b	9	11				b					
c	2	02				c	2	02				c					
d	0	00				d	FMT	42				d					
a 0	0	00				d 0	y→()	40									
1	FMT	42				1	1	01									
2	y→()	40				2	9	11									
3	1	01				3	1	01									
4	9	11				4	FMT	42									
5	9	11				5	y→()	40									
6	FMT	42				6	3	03									
7	y→()	40				7	FMT	42									
8	1	01				8	GO TO	44									
9	9	11				9	END	46									
a	8	10				a											
b	FMT	42				b											
c	y→()	40				c											
d	1	01				d											

Storage

f	
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d	
c	
b	
a	
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3	
2	
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0	

Title LAUNCH SIMULATION P3 PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	0	00			
02	↑	27			
03	1	01			
04	9	11			
05	0	00			
06	FMT	42			
07	y→()	40			
08	1	01			
09	8	10			
0a	9	11			
0b	FMT	42			
0c	y→()	40			
0d	1	01			
10	8	10			
11	8	10			
12	FMT	42			
13	y→()	40			
14	1	01			
15	6	06			
16	3	03			
17	FMT	42			
18	π	56			
19	↑	27			
1a	2	02			
1b	1	01			
1c	0	00			
1d	FMT	42			
20	y→()	40			
21	2	02			
22	2	02			
23	4	04			
24	FMT	42			
25	π	56			
26	↑	27			
27	x	36			
28	3	03			
29	9	11			
2a	.	21			
2b	4	04			
2c	7	07			
2d	8	10			

Step	Key	Code	Display x	Display y	Display z
30	x	36			
31	2	02			
32	1	01			
33	9	11			
34	FMT	42			
35	π	56			
36	x	36			
37	y→()	40			
38	f	15			
39	2	02			
3a	4	04			
3b	2	02			
3c	FMT	42			
3d	π	56			
40	↑	27			
41	2	02			
42	4	04			
43	3	03			
44	FMT	42			
45	π	56			
46	−	34			
47	2	02			
48	0	00			
49	5	05			
4a	FMT	42			
4b	π	56			
4c	↑	27			
4d	y→()	40			
50	e	12			
51	2	02			
52	0	00			
53	6	06			
54	FMT	42			
55	π	56			
56	+	33			
57	2	02			
58	2	02			
59	2	02			
5a	FMT	42			
5b	π	56			
5c	x	36			
5d	2	02			

Step	Key	Code	Display x	Display y	Display z
60	0	00			
61	7	07			
62	FMT	42			
63	π	56			
64	x⇄y	30			
65	−	34			
66	↓	25			
67	x	36			
68	2	02			
69	0	00			
6a	6	06			
6b	FMT	42			
6c	π	56			
6d	↑	27			
70	2	02			
71	4	04			
72	0	00			
73	FMT	42			
74	π	56			
75	x	36			
76	↓	25			
77	+	33			
78	2	02			
79	4	04			
7a	1	01			
7b	FMT	42			
7c	π	56			
7d	↑	27			

Storage	
f	
e	
d	
c	
b	
a	
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8	
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3	
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1	
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Title LAUNCH SIMULATION P_3 PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
80	e	12			
1	x	36			
2	↓	25			
3	−	34			
4	2	02			
5	1	01			
6	6	06			
7	FMT	42			
8	π	56			
9	x→()	23			
a	e	12			
b	cos x	73			
c	↑	27			
d	2	02			
90	2	02			
1	5	05			
2	FMT	42			
3	π	56			
4	x	36			
5	2	02			
6	3	03			
7	9	11			
8	FMT	42			
9	π	56			
a	x	36			
b	↓	25			
c	−	34			
d	e	12			
a0	sin x	70			
1	↑	27			
2	2	02			
3	2	02			
4	5	05			
5	FMT	42			
6	π	56			
7	x	36			
8	2	02			
9	3	03			
a	8	10			
b	FMT	42			
c	π	56			
d	x	36			
b0	↓	25			
1	+	33			
2	f	15			
3	÷	35			
4	1	01			
5	8	10			
6	6	06			
7	FMT	42			
8	y→()	40			
9	CLEAR	20			
a	↑	27			
b	1	01			
c	8	10			
d	5	05			
c0	FMT	42			
1	y→()	40			
2	STOP	41			
3	END	46			

Storage

f	
e	
d	
c	
b	
a	
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8	
7	
6	
5	
4	
3	
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1	
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Title LAUNCH SIMULATION P2a PAGE 1 OF 2

Step	Key	Code	Display x	y	z
00	1	01			
1	8	10			
2	8	10			
3	FMT	42			
4	π	56			
5	x→( )	23			
6	f	15			
7	↑	27			
8	2	02			
9	3	03			
a	5	05			
b	FMT	42			
c	π	56			
d	IF x<y	52			
10	2	02			
1	0	00			
2	÷	35			
3	↑	27			
4	2	02			
5	3	03			
6	0	00			
7	FMT	42			
8	π	56			
9	ROLL ↑	22			
a	x	36			
b	GO TO	44			
c	d	17			
d	2	02			
20	↑	27			
1	2	02			
2	3	03			
3	4	04			
4	FMT	42			
5	π	56			
6	x→( )	23			
7	e	12			
8	ROLL ↑	22			
9	x⇄y	30			
a	IF x<y	52			
b	4	04			
c	d	17			
d	ROLL ↑	22			

Step	Key	Code	Display x	y	z
30	−	34			
1	ROLL ↑	22			
2	x⇄y	30			
3	−	34			
4	↓	25			
5	x⇄y	30			
6	÷	35			
7	2	02			
8	3	03			
9	0	00			
a	FMT	42			
b	π	56			
c	↑	27			
d	2	02			
40	2	02			
1	9	11			
2	FMT	42			
3	π	56			
4	x⇄y	30			
5	−	34			
6	ROLL ↓	31			
7	x	36			
8	↓	25			
9	+	33			
a	GO TO	44			
b	d	17			
c	2	02			
d	e	12			
50	↑	27			
1	f	15			
2	↑	27			
3	2	02			
4	3	03			
5	3	03			
6	FMT	42			
7	π	56			
8	x→( )	23			
9	e	12			
a	IF x<y	52			
b	7	07			
c	c	16			
d	ROLL ↑	22			

Step	Key	Code	Display x	y	z
60	−	34			
1	ROLL ↑	22			
2	x⇄y	30			
3	−	34			
4	↓	25			
5	x⇄y	30			
6	÷	35			
7	2	02			
8	2	02			
9	8	10			
a	FMT	42			
b	π	56			
c	↑	27			
d	2	02			
70	2	02			
1	9	11			
2	FMT	42			
3	π	56			
4	−	34			
5	ROLL ↓	31			
6	x	36			
7	↓	25			
8	+	33			
9	GO TO	44			
a	d	17			
b	2	02			
c	e	12			
d	↑	27			

Storage

f	t
e	T2, T3, T4
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
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1	
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Title LAUNCH SIMULATION P20 PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
80	f	15			
1	↑	27			
2	2	02			
3	3	03			
4	2	02			
5	FMT	42			
6	π	56			
7	x→()	23			
8	e	12			
9	IF x<y	52			
a	a	13			
b	b	14			
c	ROLL ↑	22			
d	−	34			
90	ROLL ↑	22			
1	x⇄y	30			
2	−	34			
3	↓	25			
4	x⇄y	30			
5	÷	35			
6	2	02			
7	2	02			
8	7	07			
9	FMT	42			
a	π	56			
b	↑	27			
c	2	02			
d	2	02			
a0	8	10			
1	FMT	42			
2	π	56			
3	−	34			
4	ROLL ↓	31			
5	×	36			
6	↓	25			
7	+	33			
8	GO TO	44			
9	d	17			
a	2	02			
b	e	12			
c	↑	27			
d	f	15			

Step	Key	Code	Display x	Display y	Display z
b0	↑	27			
1	2	02			
2	3	03			
3	1	01			
4	FMT	42			
5	π	56			
6	IF x<y	52			
7	d	17			
8	0	00			
9	ROLL ↑	22			
a	−	34			
b	ROLL ↑	22			
c	x⇄y	30			
d	−	34			
c0	↓	25			
1	x⇄y	30			
2	÷	35			
3	2	02			
4	2	02			
5	7	07			
6	FMT	42			
7	π	56			
8	×	36			
9	x⇄y	30			
a	−	34			
b	GO TO	44			
c	d	17			
d	2	02			
d0	CLEAR X	37			
1	↑	27			
2	2	02			
3	0	00			
4	4	04			
5	FMT	42			
6	y→()	40			
7	2	02			
8	5	05			
9	FMT	42			
a	GO TO	44			
b	END	46			
c					
d					

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P_{25} PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	2	02			
02	0	00			
03	3	03			
04	FMT	42			
05	π	56			
06	x→()	23			
07	f	15			
08	2	02			
09	1	01			
0a	0	00			
0b	FMT	42			
0c	π	56			
0d	SIN x	70			
10	↑	27			
11	|y|	55			
12	2	02			
13	2	02			
14	6	06			
15	FMT	42			
16	π	56			
17	↑	27			
18	3	03			
19	2	02			
1a	.	21			
1b	2	02			
1c	÷	35			
1d	y→()	40			
20	e	12			
21	↓	25			
22	x	36			
23	2	02			
24	0	00			
25	2	02			
26	FMT	42			
27	π	56			
28	x	36			
29	x	36			
2a	2	02			
2b	4	04			
2c	5	05			
2d	FMT	42			

Step	Key	Code	Display x	Display y	Display z
30	π	56			
31	x	36			
32	2	02			
33	0	00			
34	6	06			
35	FMT	42			
36	π	56			
37	↑	27			
38	|y|	55			
39	↓	25			
3a	+	33			
3b	2	02			
3c	0	00			
3d	5	05			
40	FMT	42			
41	π	56			
42	↑	27			
43	|y|	55			
44	↓	25			
45	+	33			
46	2	02			
47	2	02			
48	2	02			
49	FMT	42			
4a	π	56			
4b	x	36			
4c	1	01			
4d	8	10			
50	4	04			
51	FMT	42			
52	y→()	40			
53	2	02			
54	4	04			
55	3	03			
56	FMT	42			
57	π	56			
58	x	36			
59	2	02			
5a	0	00			
5b	4	04			
5c	FMT	42			
5d	π	56			

Step	Key	Code	Display x	Display y	Display z
60	↑	27			
61	2	02			
62	0	00			
63	S	11			
64	FMT	42			
65	π	56			
66	x	36			
67	↓	25			
68	x⇄y	30			
69	−	34			
6a	2	02			
6b	4	04			
6c	5	05			
6d	FMT	42			
70	π	56			
71	↑	27			
72	x	36			
73	e	12			
74	x	36			
75	2	02			
76	2	02			
77	0	00			
78	FMT	42			
79	π	56			
7a	+	33			
7b	↓	25			
7c	÷	35			
7d	y→()	40			

Storage

Register	Contents	
f	$\ddot{r}_o$	$\bar{r}_o$
e	XMI	$\dot{r}$
d		
c		
b		
a		
9		
8		
7		
6		
5		
4		
3		
2		
1		
0		

Title LAUNCH SIMULATION P25

Step	Key	Code	Display x	Display y	Display z
8 0	−	34			
1	e	12			
2	2	02			
3	0	00			
4	3	03			
5	FMT	42			
6	y→()	40			
7	2	02			
8	0	00			
9	2	02			
a	FMT	42			
b	π	56			
c	x→()	23			
d	−	34			
9 0	f	15			
1	f	15			
2	+	33			
3	2	02			
4	÷	35			
5	2	02			
6	1.	01			
7	8	10			
8	FMT	42			
9	π	56			
a	x	36			
b	x←()	67			
c	−	34			
d	f	15			
a 0	+	33			
1	2	02			
2	0	00			
3	2	02			
4	FMT	42			
5	y→()	40			
6	x←()	67			
7	−	34			
8	f	15			
9	+	33			
a	2	02			
b	÷	35			
c	2	02			
d	1	01			

Step	Key	Code	Display x	Display y	Display z
b 0	8	10			
1	FMT	42			
2	π	56			
3	x	36			
4	2	02			
5	1	01			
6	0	00			
7	FMT	42			
8	π	56			
9	+	33			
a	2	02			
b	1	01			
c	0	00			
d	FMT	42			
c 0	y→()	40			
1	2	02			
2	6	06			
3	FMT	42			
4	GO TO	44			
5	END	46			
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P26

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	1	01			
02	8	10			
03	4	04			
04	FMT	42			
05	π	56			
06	↑	27			
07	2	02			
08	0	00			
09	4	04			
0a	FMT	42			
0b	π	56			
0c	−	34			
0d	2	02			
10	1	01			
11	6	06			
12	FMT	42			
13	π	56			
14	SIN X	70			
15	↑	27			
16	2	02			
17	2	02			
18	6	06			
19	FMT	42			
1a	π	56			
1b	x	36			
1c	↓	25			
1d	+	33			
20	0	00			
21	IF X<Y	52			
22	2	02			
23	5	05			
24	↑	27			
25	2	02			
26	0	00			
27	7	07			
28	FMT	42			
29	y→()	40			
2a	CONT	47			
2b					
2c					
2d					

Step	Key	Code	Display x	Display y	Display z
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
3a					
3b					
3c					
3d	CONT	47			
40	1	01			
41	9	11			
42	7	07			
43	FMT	42			
44	π	56			
45	X→()	23			
46	f	15			
47	2	02			
48	1	01			
49	6	06			
4a	FMT	42			
4b	π	56			
4c	SIN X	70			
4d	↑	27			
50	2	02			
51	2	02			
52	6	06			
53	FMT	42			
54	π	56			
55	x	36			
56	1	01			
57	8	10			
58	4	04			
59	FMT	42			
5a	π	56			
5b	+	33			
5c	2	02			
5d	0	00			

Step	Key	Code	Display x	Display y	Display z
60	7	07			
61	FMT	42			
62	π	56			
63	x⇄y	30			
64	−	34			
65	2	02			
66	0	00			
67	4	04			
68	FMT	42			
69	π	56			
6a	+	33			
6b	2	02			
6c	2	02			
6d	6	06			
70	FMT	42			
71	π	56			
72	↑	27			
73	3	03			
74	2	02			
75	.	21			
76	2	02			
77	÷	35			
78	↓	25			
79	÷	35			
7a	y→()	40			
7b	e	12			
7c	1	01			
7d	9	11			

Storage

Register	Contents
f	$\ddot{x}_0$, $\dot{x}_0$
e	$\ddot{x}_1$
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P_{26} PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
8 0	7	07			
1	FMT	42			
2	y→()	40			
3	f	15			
4	+	33			
5	2	02			
6	÷	35			
7	2	02			
8	1	01			
9	8	10			
a	FMT	42			
b	π	56			
c	x	36			
d	↑	27			
9 0	ROLL ↓	31			
1	1	01			
2	9	11			
3	6	06			
4	FMT	42			
5	π	56			
6	+	33			
7	x→()	23			
8	f	15			
9	1	01			
a	9	11			
b	6	06			
c	FMT	42			
d	y→()	40			
a 0	f	15			
1	+	33			
2	2	02			
3	÷	35			
4	↓	25			
5	x	36			
6	1	01			
7	9	11			
8	5	05			
9	FMT	42			
a	π	56			
b	+	33			
c	1	01			
d	9	11			

Step	Key	Code	Display x	Display y	Display z
b 0	5	05			
1	FMT	42			
2	y→()	40			
3	3	03			
4	0	00			
5	FMT	42			
6	GO TO	44			
7	END	46			
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P_{30} PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
0 0	CONT	47			
1	2	02			
2	4	04			
3	3	03			
4	FMT	42			
5	π	56			
6	↑	27			
7	2	02			
8	4	04			
9	2	02			
a	FMT	42			
b	π	56			
c	x→()	23			
d	e	12			
1 0	y→()	40			
1	f	15			
2	2	02			
3	0	00			
4	5	05			
5	FMT	42			
6	π	56			
7	↑	27			
8	0	00			
9	IF x<y	52			
a	2	02			
b	9	11			
c	CONT	47			
d	f	15			
2 0	↑	27			
1	e	12			
2	+	33			
3	↓	25			
4	CHG SIGN	32			
5	↑	27			
6	GO TO	44			
7	2	02			
8	d	17			
9	e	12			
a	↑	27			
b	f	15			
c	−	34			
d	CONT	47			
3 0	1	01			
1	8	10			
2	3	03			
3	FMT	42			
4	y→()	40			
5	2	02			
6	0	00			
7	6	06			
8	FMT	42			
9	π	56			
a	↑	27			
b	0	00			
c	IF x<y	52			
d	4	04			
4 0	b	14			
1	e	12			
2	↑	27			
3	f	15			
4	+	33			
5	↓	25			
6	CHG SIGN	32			
7	↑	27			
8	GO TO	44			
9	5	05			
a	1	01			
b	e	12			
c	↑	27			
d	f	15			
5 0	−	34			
1	CONT	47			
2	1	01			
3	8	10			
4	2	02			
5	FMT	42			
6	y→()	40			
7	1	01			
8	9	11			
9	5	05			
a	FMT	42			
b	π	56			
c	↑	27			
d	2	02			
6 0	1	01			
1	5	05			
2	FMT	42			
3	π	56			
4	IF x<y	52			
5	6	06			
6	d	17			
7	CONT	47			
8	0	00			
9	↑	27			
a	GO TO	44			
b	c	16			
c	8	10			
d	↑	27			
7 0	↓	25			
1	−	34			
2	y→()	40			
3	f	15			
4	↓	25			
5	2	02			
6	1	01			
7	4	04			
8	FMT	42			
9	π	56			
a	IF x<y	52			
b	9	11			
c	4	04			
d	↑	27			

Storage

f	D_E, $x-U_1$, $x-U_2$
e	D_1
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P_3 PAGE 2 OF 2

Step	Key	Code	Display x	y	z
8 0	2	02			
1	1	01			
2	5	05			
3	FMT	42			
4	π	56			
5	−	34			
6	2	02			
7	1	01			
8	2	02			
9	FMT	42			
a	π	56			
b	x⇄y	30			
c	÷	35			
d	f	15			
9 0	x	36			
1	GO TO	44			
2	C	16			
3	8	10			
4	↑	27			
5	↓	25			
6	−	34			
7	y→( )	40			
8	f	15			
9	↓	25			
a	2	02			
b	1	01			
c	3	03			
d	FMT	42			
a 0	π	56			
1	IF x<y	52			
2	C	16			
3	5	05			
4	↑	27			
5	2	02			
6	1	01			
7	4	04			
8	FMT	42			
9	π	56			
a	−	34			
b	2	02			
c	1	01			
d	1	01			
b 0	FMT	42			
1	π	56			
2	↑	27			
3	2	02			
4	1	01			
5	2	02			
6	FMT	42			
7	π	56			
8	−	34			
9	ROLL ↓	31			
a	x⇄y	30			
b	÷	35			
c	f	15			
d	x	36			
c 0	↓	25			
1	+	33			
2	GO TO	44			
3	C	16			
4	8	10			
5	CONT	47			
6	0	00			
7	↑	27			
8	CONT	47			
9	2	02			
a	0	00			
b	8	10			
c	FMT	42			
d	y→( )	40			
d 0	3	03			
1	5	05			
2	FMT	42			
3	GO TO	44			
4	END	46			
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	y	z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

Register	Contents
f	
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1	
0	

Title LAUNCH SIMULATION P35

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	1	01			
02	9	11			
03	5	05			
04	FMT	42			
05	π	56			
06	↑	27			
07	x→()	23			
08	f	15			
09	2	02			
0a	4	04			
0b	1	01			
0c	FMT	42			
0d	π	56			
10	+	33			
11	1	01			
12	8	10			
13	3	03			
14	FMT	42			
15	π	56			
16	↑	27			
17	2	02			
18	2	02			
19	2	02			
1a	FMT	42			
1b	π	56			
1c	x	36			
1d	ROLL ↓	31			
20	+	33			
21	1	01			
22	8	10			
23	1	01			
24	FMT	42			
25	y→()	40			
26	↓	25			
27	1	01			
28	8	10			
29	2	02			
2a	FMT	42			
2b	π	56			
2c	x	36			
2d	f	15			

Step	Key	Code	Display x	Display y	Display z
30	+	33			
31	↓	25			
32	CHG SIGN	32			
33	↑	27			
34	2	02			
35	4	04			
36	0	00			
37	FMT	42			
38	π	56			
39	+	33			
3a	1	01			
3b	8	10			
3c	0	00			
3d	FMT	42			
40	y→()	40			
41	2	02			
42	1	01			
43	6	06			
44	FMT	42			
45	π	56			
46	↑	27			
47	COS X	73			
48	x⇄y	30			
49	SIN X	70			
4a	x→()	23			
4b	e	12			
4c	y→()	40			
4d	−	34			
50	f	15			
51	1	01			
52	9	11			
53	2	02			
54	FMT	42			
55	π	56			
56	↑	27			
57	ROLL ↓	31			
58	COS X	73			
59	x→()	23			
5a	−	34			
5b	e	12			
5c	x	36			
5d	ROLL ↑	22			

Step	Key	Code	Display x	Display y	Display z
60	SIN X	70			
61	x→()	23			
62	−	34			
63	d	17			
64	x⇄y	30			
65	e	12			
66	x	36			
67	↓	25			
68	+	33			
69	2	02			
6a	3	03			
6b	9	11			
6c	FMT	42			
6d	π	56			
70	x	36			
71	y→()	40			
72	−	34			
73	c	16			
74	e	12			
75	↑	27			
76	x←()	67			
77	−	34			
78	e	12			
79	x	36			
7a	x←()	67			
7b	−	34			
7c	f	15			
7d	↑	27			

Storage

f	X_i	H1
e	H2, W1	H5
d		H6
c		$D_0 P1$
b		$D_1 - D_2$
a		$D_2 - D_3 H_7$
9		H4
8		H3
7		22A
6		
5		
4		
3		
2		
1		
0		

Title LAUNCH SIMULATION P35 PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
80	x←()	67			
81	−	34			
82	d	17			
83	x	36			
84	↓	25			
85	−	34			
86	2	02			
87	3	03			
88	8	10			
89	FMT	42			
8a	π	56			
8b	x	36			
8c	CONT	47			
8d	x←()	67			
90	−	34			
91	c	16			
92	x⇄y	30			
93	−	34			
94	2	02			
95	2	02			
96	5	05			
97	FMT	42			
98	π	56			
99	x	36			
9a	2	02			
9b	4	04			
9c	2	02			
9d	FMT	42			
a0	π	56			
a1	↑	27			
a2	2	02			
a3	4	04			
a4	3	03			
a5	FMT	42			
a6	π	56			
a7	−	34			
a8	y→()	40			
a9	−	34			
aa	b	14			
ab	2	02			
ac	0	00			
ad	7	07			

Step	Key	Code	Display x	Display y	Display z
b0	FMT	42			
b1	π	56			
b2	x	36			
b3	↓	25			
b4	−	34			
b5	2	02			
b6	4	04			
b7	2	02			
b8	FMT	42			
b9	π	56			
ba	↑	27			
bb	2	02			
bc	0	00			
bd	8	10			
c0	FMT	42			
c1	π	56			
c2	x	36			
c3	↓	25			
c4	−	34			
c5	1	01			
c6	7	07			
c7	9	11			
c8	FMT	42			
c9	y→()	40			
ca	3	03			
cb	6	06			
cc	FMT	42			
cd	GO TO	44			
d0	END	46			

Storage

Title LAUNCH SIMULATION P_{36} PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
1	2	02			
2	4	04			
3	0	00			
4	FMT	42			
5	π	56			
6	↑	27			
7	x←()	67			
8	−	34			
9	e	12			
a	x	36			
b	↑	27			
c	f	15			
d	x	36			
10	↓	25			
1	−	34			
2	x←()	67			
3	−	34			
4	b	14			
5	↑	27			
6	x←()	67			
7	−	34			
8	d	17			
9	x	36			
a	↓	25			
b	−	34			
c	1	01			
d	7	07			
20	8	10			
1	FMT	42			
2	y→()	40			
3	2	02			
4	4	04			
5	3	03			
6	FMT	42			
7	π	56			
8	↑	27			
9	2	02			
a	1	01			
b	0	00			
c	FMT	42			
d	π	56			

Step	Key	Code	Display x	Display y	Display z
30	cos x	73			
1	↑	27			
2	2	02			
3	4	04			
4	5	05			
5	FMT	42			
6	π	56			
7	x	36			
8	↓	25			
9	−	34			
a	y→()	40			
b	−	34			
c	a	13			
d	1	01			
40	8	10			
1	9	11			
2	FMT	42			
3	π	56			
4	↑	27			
5	SIN X	70			
6	x⇄y	30			
7	cos x	73			
8	y→()	40			
9	−	34			
a	9	11			
b	x→()	23			
c	−	34			
d	8	10			
50	ROLL ↓	31			
1	x	36			
2	ROLL ↑	22			
3	x⇄y	30			
4	2	02			
5	4	p4			
6	6	06			
7	FMT	42			
8	π	56			
9	x	36			
a	↓	25			
b	+	33			
c	1	01			
d	7	07			

Step	Key	Code	Display x	Display y	Display z
60	7	07			
1	FMT	42			
2	y→()	40			
3	2	02			
4	4	04			
5	0	00			
6	FMT	42			
7	π	56			
8	↑	27			
9	f	15			
a	[illegible]	4			
b	[illegible]	67			
c	−	34			
d	d	17			
70	x	36			
1	x←()	67			
2	−	34			
3	e	12			
4	↑	27			
5	x←()	67			
6	−	34			
7	b	14			
8	x	36			
9	↓	25			
a	+	33			
b	1	01			
c	9	11			
d	3	03			

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
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Title LAUNCH SIMULATION P36 PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
8 0	FMT	42				b 0	9	11				0					
1	π	56				1	3	03				1					
2	x	36				2	FMT	42				2					
3	CHG SIGN	32				3	π	56				3					
4	x	36				4	x	36				4					
5	x←()	67				5	1	01				5					
6	−	34				6	9	11				6					
7	a	13				7	6	06				7					
8	↑	27				8	FMT	42				8					
9	x←()	67				9	π	56				9					
a	−	34				a	x	36				a					
b	8	10				b	2	02				b					
c	x	36				c	x	36				c					
d	ROLL ↓	31				d	↓	25				d					
9 0	y→()	40				c 0	+	33				0					
1	−	34				1	x←()	67				1					
2	7	07				2	−	34				2					
3	ROLL ↑	22				3	7	07				3					
4	2	02				4	x⇄y	30				4					
5	4	04				5	−	34				5					
6	6	06				6	1	01				6					
7	FMT	42				7	7	07				7					
8	π	56				8	6	06				8					
9	↑	27				9	FMT	42				9					
a	x←()	67				a	y→()	40				a					
b	−	34				b	2	02				b					
c	9	11				c	2	22				c					
d	x	36				d	6	06				d					
a 0	↓	25				d 0	FMT	42									
1	−	34				1	π	56									
2	1	01				2	x→()	23									
3	9	11				3	e	12									
4	0	00				4	3	03									
5	FMT	42				5	7	07									
6	π	56				6	FMT	42									
7	x	36				7	GO TO	44									
8	x	36				8	END	46									
9	x←()	67				9											
a	−	34				a											
b	e	12				b											
c	↑	27				c											
d	1	01				d											

Storage

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Title LAUNCH SIMULATION P37 PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
00	CONT	47				30	↓	25				60	y→()	40			
1	e	12				1	+	33				1	2	02			
2	↑	27				2	x←()	67				2	4	04			
3	3	03				3	−	34				3	7	07			
4	2	02				4	9	11				4	FMT	42			
5	.	21				5	↑	27				5	π	56			
6	2	02				6	2	02				6	↑	27			
7	÷	35				7	0	00				7	2	02			
8	y→()	40				8	4	04				8	4	04			
9	f	15				9	FMT	42				9	3	03			
a	2	02				a	π	56				a	FMT	42			
b	1	01				b	x	36				b	π	56			
c	0	00				c	↓	25				c	↑	27			
d	FMT	42				d	+	33				d	2	02			
10	π	56				40	1	01				70	2	02			
1	cos x	73				1	7	07				1	2	02			
2	↑	27				2	6	06				2	FMT	42			
3	x←()	67				3	FMT	42				3	π	56			
4	−	34				4	π	56				4	x	36			
5	8	10				5	↑	27				5	↓	25			
6	x	36				6	f	15				6	−	34			
7	f	15				7	x	36				7	y→()	40			
8	x	36				8	↓	25				8	−	34			
9	2	02				9	+	33				9	f	15			
a	0	00				a	x←()	67				a	↑	27			
b	2	02				b	−	34				b	2	02			
c	FMT	42				c	d	17				c	4	04			
d	π	56				d	↑	27				d	6	06			
20	x	36				50	1	01									
1	x	36				1	9	11									
2	2	02				2	7	07									
3	4	04				3	FMT	42									
4	5	05				4	π	56									
5	FMT	42				5	x	36									
6	π	56				6	f	15									
7	x	36				7	x	36									
8	x←()	67				8	↓	25									
9	−	34				9	−	34									
a	f	15				a	1	01									
b	↑	27				b	7	07									
c	e	12				c	5	05									
d	x	36				d	FMT	42									

Storage

Reg	Contents	
f	XMI	E1
e	WI	E2
d		E3
c		E5
b		E6
a		E4
9		E7
8		E8
7		E9
6		S
5		
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Title LAUNCH SIMULATION P37 PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
80	FMT	42				b0	y→()	40				0					
1	π	56				1	−	34				1					
2	+	33				2	c	16				2					
3	y→()	40				3	↑	27				3					
4	−	34				4	2	02				4					
5	e	12				5	2	02				5					
6	2	02				6	1	01				6					
7	4	04				7	FMT	42				7					
8	4	04				8	π	56				8					
9	FMT	42				9	x⇄y	30				9					
a	π	56				a	÷	35				a					
b	↑	27				b	y→()	40				b					
c	2	02				c	−	34				c					
d	4	04				d	b	14				d					
90	5	05				c0	↑	27				0					
1	FMT	42				1	x←()	67				1					
2	π	56				2	−	34				2					
3	+	33				3	e	12				3					
4	2	02				4	x⇄y	30				4					
5	1	01				5	÷	35				5					
6	0	00				6	y→()	40				6					
7	FMT	42				7	−	34				7					
8	π	56				8	9	11				8					
9	cos x	73				9	↑	27				9					
a	x	36				a	x←()	61				a					
b	y→()	40				b	−	34				b					
c	−	34				c	d	17				c					
d	d	17				d	x⇄y	30				d					
a0	x←()	67				d0	÷	35									
1	−	34				1	y→()	40									
2	f	15				2	−	34									
3	↑	27				3	8	10									
4	x←()	67				4	ROLL ↓	31									
5	−	34				5	↓	25									
6	e	12				6	↓	25									
7	+	33				7	CONT	47									
8	↑	27				8	CONT	47									
9	f	15				9	3	03									
a	x	36				a	8	10									
b	↓	25				b	FMT	42									
c	x⇄y	30				c	GO TO	44									
d	÷	35				d	END	46									

Storage

Register	
f	
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Title LAUNCH SIMULATION P38 PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	↓	25			
02	x←()	67			
03	−	34			
04	a	13			
05	x⇄y	30			
06	÷	35			
07	y→()	40			
08	−	34			
09	7	07			
0a	x←()	67			
0b	−	34			
0c	c	16			
0d	↑	27			
10	1	01			
11	7	07			
12	7	07			
13	FMT	42			
14	π	56			
15	x	36			
16	x←()	67			
17	−	34			
18	b	14			
19	+	33			
1a	1	01			
1b	7	07			
1c	4	04			
1d	FMT	42			
20	y→()	40			
21	1	01			
22	7	07			
23	5	05			
24	FMT	42			
25	π	56			
26	↑	27			
27	x←()	67			
28	−	34			
29	9	11			
2a	x	36			
2b	2	02			
2c	0	00			
2d	4	04			

Step	Key	Code	Display x	Display y	Display z
30	FMT	42			
31	π	56			
32	↑	27			
33	x←()	67			
34	−	34			
35	8	10			
36	x	36			
37	↓	25			
38	+	33			
39	2	02			
3a	0	00			
3b	7	07			
3c	FMT	42			
3d	π	56			
40	↑	27			
41	x←()	67			
42	−	34			
43	7	07			
44	x	36			
45	↓	25			
46	−	34			
47	1	01			
48	7	07			
49	3	03			
4a	FMT	42			
4b	y→()	40			
4c	1	01			
4d	8	10			
50	0	00			
51	FMT	42			
52	π	56			
53	↑	27			
54	1	01			
55	7	07			
56	8	10			
57	FMT	42			
58	π	56			
59	x	36			
5a	f	15			
5b	x	36			
5c	2	02			
5d	1	01			

Step	Key	Code	Display x	Display y	Display z
60	9	11			
61	FMT	42			
62	π	56			
63	÷	33			
64	1	01			
65	7	07			
66	2	02			
67	FMT	42			
68	y→()	40			
69	1	01			
6a	7	07			
6b	7	07			
6c	FMT	42			
6d	π	56			
70	↑	27			
71	1	01			
72	8	10			
73	0	00			
74	FMT	42			
75	π	56			
76	x	36			
77	f	15			
78	x	36			
79	1	01			
7a	7	07			
7b	1	01			
7c	FMT	42			
7d	y→()	40			

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
9	
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4	
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Step	Key	Code	Display			Step	Key	Code	Display			Step	Key	Code	Display		
			x	y	z				x	y	z				x	y	z
8 0	1	01				b 0	1	01				0					
1	7	07				1	FMT	42				1					
2	7	07				2	π	56				2					
3	FMT	42				3	x	36				3					
4	π	56				4	1	01				4					
5	↑	27				5	7	07				5					
6	f	15				6	0	00				6					
7	x	36				7	FMT	42				7					
8	x←()	67				8	π	56				8					
9	−	34				9	↑	27				9					
a	e	12				a	1	01				a					
b	x	36				b	7	07				b					
c	2	02				c	2	02				c					
d	2	02				d	FMT	42				d					
9 0	1	01				c 0	π	56				0					
1	FMT	42				1	x	36				1					
2	π	56				2	↓	25				2					
3	+	33				3	x⇄y	30				3					
4	1	01				4	−	34				4					
5	7	07				5	1	01				5					
6	0	00				6	6	06				6					
7	FMT	42				7	8	10				7					
8	y→()	40				8	FMT	42				8					
9	1	01				9	y→()	40				9					
a	7	07				a	1	01				a					
b	8	10				b	7	07				b					
c	FMT	42				c	7	07				c					
d	π	56				d	FMT	42				d					
a 0	↑	27				d 0	π	56									
1	f	15				1	↑	27									
2	x	36				2	↑	27									
3	x←()	67				3	3	03									
4	−	34				4	9	11									
5	e	12				5	FMT	42									
6	x	36				6	GO TO	44									
7	1	01				7	END	46									
8	6	06				8											
9	9	11				9											
a	FMT	42				a											
b	y→()	40				b											
c	1	01				c											
d	7	07				d											

Storage

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Title LAUNCH SIMULATION P_{32} PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	↓	25			
02	x←()	67			
03	−	34			
04	c	16			
05	↑	27			
06	f	15			
07	−	34			
08	↓	25			
09	x	36			
0a	x←()	67			
0b	−	34			
0c	b	14			
0d	+	33			
10	1	01			
11	6	06			
12	7	07			
13	FMT	42			
14	y→()	40			
15	2	02			
16	0	00			
17	7	07			
18	FMT	42			
19	π	56			
1a	↑	27			
1b	x←()	67			
1c	−	34			
1d	7	07			
20	x	36			
21	2	02			
22	0	00			
23	4	04			
24	FMT	42			
25	π	56			
26	↑	27			
27	x←()	67			
28	−	34			
29	8	10			
2a	x	36			
2b	↓	25			
2c	−	34			
2d	1	01			

Step	Key	Code	Display x	Display y	Display z
30	↑	27			
31	x←()	67			
32	−	34			
33	9	11			
34	−	34			
35	1	01			
36	7	07			
37	5	05			
38	FMT	42			
39	π	56			
3a	x	36			
3b	ROLL ↓	31			
3c	+	33			
3d	1	01			
40	6	06			
41	6	06			
42	FMT	42			
43	y→()	40			
44	↓	25			
45	1	01			
46	8	10			
47	0	00			
48	FMT	42			
49	π	56			
4a	CHG SIGN	32			
4b	x	36			
4c	1	01			
4d	7	07			
50	9	11			
51	FMT	42			
52	π	56			
53	+	33			
54	1	01			
55	6	06			
56	5	05			
57	FMT	42			
58	y→()	40			
59	2	02			
5a	0	00			
5b	4	04			
5c	FMT	42			
5d	π	56			

Step	Key	Code	Display x	Display y	Display z
60	↑	27			
61	x←()	67			
62	−	34			
63	d	17			
64	x	36			
65	1	01			
66	7	07			
67	5	05			
68	FMT	42			
69	π	56			
6a	↑	27			
6b	x←()	67			
6c	−	34			
6d	e	12			
70	x	36			
71	↓	25			
72	+	33			
73	1	01			
74	6	06			
75	4	04			
76	FMT	42			
77	y→()	40			
78	2	02			
79	2	02			
7a	4	04			
7b	FMT	42			
7c	π	56			
7d	↑	27			

Storage

Register	Contents
f	–
e	
d	
c	
b	
a	
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5	c
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Title LAUNCH SIMULATION P3

Step	Key	Code	Display x	Display y	Display z
8 0	x	36			
1	π	56			
2	↑	27			
3	x	36			
4	4	04			
5	x	36			
6	↓	25			
7	x	36			
8	1	01			
9	6	06			
a	2	02			
b	FMT	42			
c	π	56			
d	x	36			
9 0	y→( )	40			
1	−	34			
2	6	06			
3	x	36			
4	4	04			
5	x	36			
6	2	02			
7	2	02			
8	3	03			
9	FMT	42			
a	π	56			
b	x	36			
c	x	36			
d	↓	25			
a 0	$\sqrt{x}$	76			
1	x→( )	23			
2	−	34			
3	5	05			
4	4	04			
5	0	00			
6	FMT	42			
7	GO TO	44			
8	END	46			
9					
a					
b					
c					
d					

Storage

Title LAUNCH SIMULATION P40 CASE I PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	1	01			
02	9	11			
03	4	04			
04	FMT	42			
05	π	56			
06	x→()	23			
07	e	12			
08	2	02			
09	1	01			
0a	9	11			
0b	FMT	42			
0c	π	56			
0d	↑	27			
10	x←()	67			
11	−	34			
12	c	16			
13	↑	27			
14	1	01			
15	7	07			
16	8	10			
17	FMT	42			
18	π	56			
19	x	36			
1a	1	01			
1b	8	10			
1c	1	01			
1d	FMT	42			
20	π	56			
21	x	36			
22	ROLL↓	31			
23	−	34			
24	ROLL↑	22			
25	x⇄y	30			
26	1	01			
27	7	07			
28	4	04			
29	FMT	42			
2a	π	56			
2b	x	36			
2c	↓	25			
2d	+	33			

Step	Key	Code	Display x	Display y	Display z
30	x←()	67			
31	−	34			
32	c	16			
33	↑	27			
34	f	15			
35	−	34			
36	1	01			
37	7	07			
38	8	10			
39	FMT	42			
3a	π	56			
3b	x	36			
3c	1	01			
3d	8	10			
40	0	00			
41	FMT	42			
42	π	56			
43	x	36			
44	ROLL↓	31			
45	−	34			
46	ROLL↑	22			
47	x⇄y	30			
48	1	01			
49	6	06			
4a	7	07			
4b	FMT	42			
4c	π	56			
4d	x	36			
50	↓	25			
51	+	33			
52	y→()	40			
53	−	34			
54	4	04			
55	↑	27			
56	1	01			
57	8	10			
58	6	06			
59	FMT	42			
5a	π	56			
5b	↑	27			
5c	1	01			
5d	9	11			

Step	Key	Code	Display x	Display y	Display z
60	2	02			
61	FMT	42			
62	π	56			
63	−	34			
64	x←()	67			
65	−	34			
66	6	06			
67	x	36			
68	1	01			
69	9	11			
6a	3	03			
6b	FMT	42			
6c	π	56			
6d	↑	27			
70	x←()	67			
71	−	34			
72	5	05			
73	x	36			
74	↓	25			
75	−	34			
76	1	01			
77	8	10			
78	1	01			
79	FMT	42			
7a	π	56			
7b	↑	27			
7c	1	01			
7d	7	07			

Storage

Register	Contents
f	XM1
e	θ̈
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c	
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Title LAUNCH SIMULATION P_{40} CASE I PAGE 2 OF 2

Step	Key	Code	x	y	z	Step	Key	Code	x	y	z	Step	Key	Code	x	y	z
8 0	3	03				b 0	e	12				0					
1	FMT	42				1	+	33				1					
2	π	56				2	2	02				2					
3	X	36				3	÷	35				3					
4	↓	25				4	2	02				4					
5	+	33				5	1	01				5					
6	1	01				6	8	10				6					
7	8	10				7	FMT	42				7					
8	0	00				8	π	56				8					
9	FMT	42				9	X	36				9					
a	π	56				a	f	15				a					
b	↑	27				b	+	33				b					
c	1	01				c	1	01				c					
d	6	06				d	9	11				d					
9 0	6	06				c 0	3	03				0					
1	FMT	42				1	FMT	42				1					
2	π	56				2	y→()	40				2					
3	X	36				3	f	15				3					
4	↓	25				4	+	33				4					
5	−	34				5	2	02				5					
6	1	01				6	÷	35				6					
7	7	07				7	2	02				7					
8	9	11				8	1	01				8					
9	FMT	42				9	8	10				9					
a	π	56				a	FMT	42				a					
b	+	33				b	π	56				b					
c	x←()	67				c	X	36				c					
d	−	34				d	1	01				d					
a 0	4	04				d 0	9	11									
1	÷	35				1	2	02									
2	1	01				2	FMT	42									
3	9	11				3	π	56									
4	4	04				4	+	33									
5	FMT	42				5	4	04									
6	y→()	40				6	1	01									
7	1	01				7	FMT	42									
8	9	11				8	GO TO	44									
9	3	03				9	END	46									
a	FMT	42				a											
b	π	56				b											
c	x→()	23				c											
d	f	15				d											

Storage

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Title: LAUNCH SIMULATION P_{41} CASE I   PAGE 1 OF 1

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	1	01			
02	9	11			
03	2	02			
04	FMT	42			
05	y→( )	40			
06	x←( )	67			
07	−	34			
08	C	16			
09	↑	27			
0a	1	01			
0b	7	07			
0c	8	10			
0d	FMT	42			
10	π	56			
11	x	36			
12	1	01			
13	7	07			
14	4	04			
15	FMT	42			
16	π	56			
17	−	34			
18	1	01			
19	9	11			
1a	4	04			
1b	FMT	42			
1c	π	56			
1d	x	36			
20	↑	27			
21	1	01			
22	9	11			
23	1	01			
24	FMT	42			
25	y→( )	40			
26	↓	25			
27	1	01			
28	7	07			
29	3	03			
2a	FMT	42			
2b	π	56			
2c	+	33			
2d	2	02			

Step	Key	Code	Display x	Display y	Display z
30	0	00			
31	5	05			
32	FMT	42			
33	y→( )	40			
34	1	01			
35	9	11			
36	3	03			
37	FMT	42			
38	π	56			
39	↑	27			
3a	1	01			
3b	9	11			
3c	0	00			
3d	FMT	42			
40	y→( )	40			
41	1	01			
42	9	11			
43	2	02			
44	FMT	42			
45	π	56			
46	↑	27			
47	1	01			
48	8	10			
49	9	11			
4a	FMT	42			
4b	y→( )	40			
4c	4	04			
4d	2	02			
50	FMT	42			
51	GO TO	44			
52	END	46			
53					
54					
55					
56					
57					
58					
59					
5a					
5b					
5c					
5d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
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3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
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1					
2					
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4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage	
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Title LAUNCH SIMULATION P_{42} CASE I PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	2	02			
02	2	02			
03	6	06			
04	FMT	42			
05	π	56			
06	↑	27			
07	3	03			
08	2	02			
09	.	21			
0a	2	02			
0b	÷	35			
0c	x←()	67			
0d	−	34			
10	c	16			
11	−	34			
12	1	01			
13	7	07			
14	8	10			
15	FMT	42			
16	π	56			
17	x	36			
18	1	01			
19	6	06			
1a	7	07			
1b	FMT	42			
1c	π	56			
1d	÷	33			
20	1	01			
21	9	11			
22	4	04			
23	FMT	42			
24	π	56			
25	x	36			
26	1	01			
27	6	06			
28	6	06			
29	FMT	42			
2a	π	56			
2b	+	33			
2c	2	02			
2d	0	00			

Step	Key	Code	Display x	Display y	Display z
30	6	06			
31	FMT	42			
32	y→()	40			
33	2	02			
34	0	00			
35	0	00			
36	FMT	42			
37	π	56			
38	x→()	23			
39	e	12			
3a	1	01			
3b	7	07			
3c	8	10			
3d	FMT	42			
40	π	56			
41	↑	27			
42	1	01			
43	7	07			
44	7	07			
45	FMT	42			
46	π	56			
47	−	34			
48	1	01			
49	9	11			
4a	4	04			
4b	FMT	42			
4c	π	56			
4d	x	36			
50	1	01			
51	9	11			
52	7	07			
53	FMT	42			
54	π	56			
55	↑	27			
56	1	01			
57	9	11			
58	2	02			
59	FMT	42			
5a	π	56			
5b	SIN X	70			
5c	x	36			
5d	↓	25			

Step	Key	Code	Display x	Display y	Display z
60	−	34			
61	1	01			
62	7	07			
63	6	06			
64	FMT	42			
65	π	56			
66	+	33			
67	2	02			
68	0	00			
69	0	00			
6a	FMT	42			
6b	y→()	40			
6c	1	01			
6d	9	11			
70	9	11			
71	FMT	42			
72	π	56			
73	x→()	23			
74	f	15			
75	e	12			
76	+	33			
77	2	02			
78	÷	35			
79	2	02			
7a	1	01			
7b	8	10			
7c	FMT	42			
7d	π	56			

Storage

f	$\dot{Y}_0$
e	$\dot{Y}_0$
d	
c	
b	
a	
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1	
0	

Title LAUNCH SIMULATION P42 CASE I PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
80	x	36			
1	f	15			
2	+	33			
3	1	01			
4	9	11			
5	9	11			
6	FMT	42			
7	y→()	40			
8	f	15			
9	+	33			
a	2	02			
b	÷	35			
c	2	02			
d	1	01			
90	8	10			
1	FMT	42			
2	π	56			
3	x	36			
4	1	01			
5	9	11			
6	8	10			
7	FMT	42			
8	π	56			
9	+	33			
a	1	01			
b	9	11			
c	8	10			
d	FMT	42			
a0	y→()	40			
1	2	02			
2	3	03			
3	7	07			
4	FMT	42			
5	π	56			
6	↑	27			
7	2	02			
8	4	04			
9	7	07			
a	FMT	42			
b	π	56			
c	−	34			
d	2	02			

Step	Key	Code	Display x	Display y	Display z
b0	4	04			
1	6	06			
2	FMT	42			
3	π	56			
4	−	34			
5	y→()	40			
6	−	34			
7	1	01			
8	+	33			
9	1	01			
a	2	02			
b	FMT	42			
c	GO TO	44			
d	END	46			

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
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4	
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1	
0	

Title LAUNCH SIMULATION P10 PAGE 1 OF 1

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
1	1	01			
2	9	11			
3	0	00			
4	FMT	42			
5	π	56			
6	↑	27			
7	1	01			
8	8	10			
9	7	07			
a	FMT	42			
b	π	56			
c	x	36			
d	1	01			
10	8	10			
1	8	10			
2	FMT	42			
3	π	56			
4	↑	27			
5	2	02			
6	0	00			
7	1	01			
8	FMT	42			
9	π	56			
a	x	36			
b	↓	25			
c	FMT	42			
d	↓	25			
20	0	00			
1	↑	27			
2	1	01			
3	8	10			
4	5	05			
5	FMT	42			
6	y→( )	40			
7	1	01			
8	1	01			
9	FMT	42			
a	GO TO	44			
b	END	46			
c					
d					

Storage

f	
e	
d	
c	
b	
a	
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6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P11 PAGE 1 OF 1

Step	Key	Code	Display x	Display y	Display z
0 0	CONT	47			
1	1	01			
2	8	10			
3	8	10			
4	FMT	42			
5	π	56			
6	↑	27			
7	2	02			
8	1	01			
9	8	10			
a	FMT	42			
b	π	56			
c	+	33			
d	1	01			
1 0	8	10			
1	8	10			
2	FMT	42			
3	y→()	40			
4	2	02			
5	0	00			
6	FMT	42			
7	GO TO	44			
8	END	46			

Storage

Title LAUNCH SIMULATION P_{12} PAGE 1 OF 1

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
1	1	01			
2	9	11			
3	5	05			
4	FMT	42			
5	π	56			
6	↑	27			
7	x←()	67			
8	−	34			
9	1	01			
a	If x<y	52			
b	3	03			
c	9	11			
d	CONT	47			
10	1	01			
1	8	10			
2	5	05			
3	FMT	42			
4	π	56			
5	↑	27			
6	2	02			
7	1	01			
8	8	10			
9	FMT	42			
a	π	56			
b	+	33			
c	1	01			
d	8	10			
20	5	05			
1	FMT	42			
2	y→()	40			
3	2	02			
4	1	01			
5	7	07			
6	FMT	42			
7	π	56			
8	If x≥y	53			
9	3	03			
a	3	03			
b	CONT	47			
c	1	01			
d	0	00			

Step	Key	Code	Display x	Display y	Display z
30	GO TO	44			
1	4	04			
2	2	02			
3	CONT	47			
4	1	01			
5	1	01			
6	GO TO	44			
7	4	04			
8	2	02			
9	CONT	47			
a	1	01			
b	↑	27			
c	0	00			
d	↑	27			
40	STOP	41			
1	CONT	47			
2	FMT	42			
3	GO TO	44			
4	END	46			
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage	
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b	
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7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P_{40} CASE II

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	0	00			
02	↑	27			
03	2	02			
04	0	00			
05	5	05			
06	FMT	42			
07	y→()	40			
08	1	01			
09	9	11			
0a	1	01			
0b	FMT	42			
0c	π	56			
0d	x→()	23			
10	e	12			
11	1	01			
12	8	10			
13	6	06			
14	FMT	42			
15	π	56			
16	↑	27			
17	1	01			
18	9	11			
19	2	02			
1a	FMT	42			
1b	π	56			
1c	−	34			
1d	x←()	67			
20	−	34			
21	6	06			
22	×	36			
23	1	01			
24	6	06			
25	9	11			
26	FMT	42			
27	π	56			
28	×	36			
29	↑	27			
2a	x←()	67			
2b	−	34			
2c	5	05			
2d	×	36			

Step	Key	Code	Display x	Display y	Display z
30	1	01			
31	9	11			
32	3	03			
33	FMT	42			
34	π	56			
35	×	36			
36	↓	25			
37	−	34			
38	1	01			
39	6	06			
3a	9	11			
3b	FMT	42			
3c	π	56			
3d	↑	27			
40	1	01			
41	6	06			
42	5	05			
43	FMT	42			
44	π	56			
45	×	36			
46	↓	25			
47	+	33			
48	1	01			
49	6	06			
4a	4	04			
4b	FMT	42			
4c	π	56			
4d	↑	27			
50	1	01			
51	7	07			
52	2	02			
53	FMT	42			
54	π	56			
55	×	36			
56	↓	25			
57	+	33			
58	1	01			
59	6	06			
5a	8	10			
5b	FMT	42			
5c	π	56			
5d	÷	35			

Step	Key	Code	Display x	Display y	Display z
60	1	01			
61	9	11			
62	1	01			
63	FMT	42			
64	y→()	40			
65	1	01			
66	9	11			
67	0	00			
68	FMT	42			
69	π	56			
6a	x→()	23			
6b	f	15			
6c	e	12			
6d	+	33			
70	2	02			
71	÷	35			
72	2	02			
73	1	01			
74	8	10			
75	FMT	42			
76	π	56			
77	×	36			
78	f	15			
79	+	33			
7a	1	01			
7b	9	11			
7c	0	00			
7d	FMT	42			

Storage

Register	Contents
f	$\dot{\theta}_0$
e	$\ddot{\theta}_0$
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P40 CASE II

Step	Key	Code	Display x	Display y	Display z
80	y→()	40			
1	f	15			
2	+	33			
3	2	02			
4	÷	35			
5	2	02			
6	1	01			
7	8	10			
8	FMT	42			
9	π	56			
a	x	36			
b	1	01			
c	8	10			
d	9	11			
90	FMT	42			
1	π	56			
2	+	33			
3	1	01			
4	8	10			
5	9	11			
6	FMT	42			
7	y→()	40			
8	4	04			
9	1	01			
a	FMT	42			
b	GO TO	44			
c	END	46			
d					

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P41 CASE II PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	1	01			
02	9	11			
03	4	04			
04	FMT	42			
05	π	56			
06	x→()	23			
07	e	12			
08	1	01			
09	8	10			
0a	6	06			
0b	FMT	42			
0c	π	56			
0d	↑	27			
10	1	01			
11	9	11			
12	2	02			
13	FMT	42			
14	π	56			
15	−	34			
16	x←()	67			
17	−	34			
18	6	06			
19	x	36			
1a	1	01			
1b	7	07			
1c	0	00			
1d	FMT	42			
20	π	56			
21	x	36			
22	↑	27			
23	x←()	67			
24	−	34			
25	5	05			
26	x	36			
27	1	01			
28	9	11			
29	3	03			
2a	FMT	42			
2b	π	56			
2c	x	36			
2d	↓	25			

Step	Key	Code	Display x	Display y	Display z
30	−	34			
31	1	01			
32	7	07			
33	1	01			
34	FMT	42			
35	π	56			
36	↑	27			
37	1	01			
38	6	06			
39	4	04			
3a	FMT	42			
3b	π	56			
3c	x	36			
3d	↓	25			
40	+	33			
41	1	01			
42	6	06			
43	5	05			
44	FMT	42			
45	π	56			
46	↑	27			
47	1	01			
48	7	07			
49	0	00			
4a	FMT	42			
4b	π	56			
4c	x	36			
4d	↓	25			
50	+	33			
51	1	01			
52	6	06			
53	8	10			
54	FMT	42			
55	π	56			
56	÷	35			
57	1	01			
58	9	11			
59	4	04			
5a	FMT	42			
5b	y→()	40			
5c	1	01			
5d	9	11			

Step	Key	Code	Display x	Display y	Display z
60	3	03			
61	FMT	42			
62	π	56			
63	x→()	23			
64	f	15			
65	e	12			
66	+	33			
67	2	02			
68	÷	35			
69	2	02			
6a	1	01			
6b	8	10			
6c	FMT	42			
6d	π	56			
70	x	36			
71	f	15			
72	+	33			
73	1	01			
74	9	11			
75	3	03			
76	FMT	42			
77	y→()	40			
78	f	15			
79	+	33			
7a	2	02			
7b	÷	35			
7c	2	02			
7d	1	01			

Storage

Register	Contents
f	ϕ_0
e	$\dot{\phi}_0$
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P41 CASE II PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
8 0	8	10			
1	FMT	42			
2	π	56			
3	x	36			
4	1	01			
5	9	11			
6	2	02			
7	FMT	42			
8	π	56			
9	+	33			
a	1	01			
b	9	11			
c	2	02			
d	FMT	42			
9 0	y→()	40			
1	1	01			
2	7	07			
3	8	10			
4	FMT	42			
5	π	56			
6	↑	27			
7	1	01			
8	9	11			
9	4	04			
a	FMT	42			
b	π	56			
c	x	36			
d	1	01			
a 0	7	07			
1	7	07			
2	FMT	42			
3	π	56			
4	↑	27			
5	1	01			
6	9	11			
7	1	01			
8	FMT	42			
9	π	56			
a	x	36			
b	↓	25			
c	−	34			
d	2	02			

Step	Key	Code	Display x	Display y	Display z
b 0	2	02			
1	6	06			
2	FMT	42			
3	π	56			
4	↑	27			
5	3	03			
6	2	02			
7	.	21			
8	2	02			
9	÷	35			
a	↓	25			
b	x	36			
c	1	01			
d	7	07			
c 0	5	05			
1	FMT	42			
2	π	56			
3	+	33			
4	2	02			
5	0	00			
6	6	06			
7	FMT	42			
8	y→()	40			
9	4	04			
a	2	02			
b	FMT	42			
c	GO TO	44			
d	END	46			
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P42 CASE II PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	2	02			
02	0	00			
03	0	00			
04	FMT	42			
05	π	56			
06	x→()	23			
07	e	12			
08	1	01			
09	7	07			
0a	8	10			
0b	FMT	42			
0c	π	56			
0d	↑	27			
10	1	01			
11	9	11			
12	4	04			
13	FMT	42			
14	π	56			
15	x	36			
16	1	01			
17	7	07			
18	7	07			
19	FMT	42			
1a	π	56			
1b	↑	27			
1c	1	01			
1d	9	11			
20	1	01			
21	FMT	42			
22	π	56			
23	x	36			
24	↓	25			
25	−	34			
26	1	01			
27	9	11			
28	7	07			
29	FMT	42			
2a	π	56			
2b	↑	27			
2c	1	01			
2d	9	11			

Step	Key	Code	Display x	Display y	Display z
30	2	02			
31	FMT	42			
32	π	56			
33	SIN X	70			
34	x	36			
35	↓	25			
36	−	34			
37	1	01			
38	7	07			
39	6	06			
3a	FMT	42			
3b	π	56			
3c	+	33			
3d	2	02			
40	0	00			
41	0	00			
42	FMT	42			
43	y→()	40			
44	1	01			
45	9	11			
46	9	11			
47	FMT	42			
48	π	56			
49	x→()	23			
4a	f	15			
4b	e	12			
4c	+	33			
4d	2	02			
50	÷	35			
51	2	02			
52	1	01			
53	8	10			
54	FMT	42			
55	π	56			
56	x	36			
57	f	15			
58	+	33			
59	1	01			
5a	9	11			
5b	9	11			
5c	FMT	42			
5d	y→()	40			

Step	Key	Code	Display x	Display y	Display z
60	f	15			
61	+	33			
62	2	02			
63	÷	35			
64	2	02			
65	1	01			
66	8	10			
67	FMT	42			
68	π	56			
69	x	36			
6a	1	01			
6b	9	11			
6c	8	10			
6d	FMT	42			
70	π	56			
71	+	33			
72	1	01			
73	9	11			
74	8	10			
75	FMT	42			
76	y→()	40			
77	2	02			
78	3	03			
79	7	07			
7a	FMT	42			
7b	π	56			
7c	x→()	23			
7d	−	34			

	Storage
f	$\dot{Y}_0$
e	$\ddot{Y}_0$
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P42 CASE II

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
8 0	1	01				0						0					
1	+	33				1						1					
2	1	01				2						2					
3	2	02				3						3					
4	FMT	42				4						4					
5	GO TO	44				5						5					
6	END	46				6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
0						0					
1						1					
2						2					
3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
a						a					
b						b					
c						c					
d						d					

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P40 CASE III PAGE 1 OF 1

Step	Key	Code
00	CONT	47
01	0	00
02	↑	27
03	2	02
04	0	00
05	5	05
06	FMT	42
07	y→()	40
08	2	02
09	0	00
0a	6	06
0b	FMT	42
0c	y→()	40
0d	1	01
10	9	11
11	1	01
12	FMT	42
13	π	56
14	x→()	23
15	e	12
16	x←()	67
17	−	34
18	d	17
19	↑	27
1a	2	02
1b	0	00
1c	4	04
1d	FMT	42
20	π	56
21	x	36
22	2	02
23	2	02
24	1	01
25	FMT	42
26	π	56
27	÷	35
28	1	01
29	9	11
2a	1	01
2b	FMT	42
2c	y→()	40
2d	1	01
30	9	11
31	0	00
32	FMT	42
33	π	56
34	x→()	23
35	f	15
36	e	12
37	+	33
38	2	02
39	÷	35
3a	2	02
3b	1	01
3c	8	10
3d	FMT	42
40	π	56
41	x	36
42	f	15
43	+	33
44	1	01
45	9	11
46	0	00
47	FMT	42
48	y→()	40
49	f	15
4a	+	33
4b	2	02
4c	÷	35
4d	2	02
50	1	01
51	8	10
52	FMT	42
53	π	56
54	x	36
55	1	01
56	8	10
57	9	11
58	FMT	42
59	π	56
5a	+	33
5b	1	01
5c	8	10
5d	9	11
60	FMT	42
61	y→()	40
62	4	04
63	1	01
64	FMT	42
65	Go To	44
66	END	46

Storage

Register	Value
f	0.
e	0.
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P41 CASE III PAGE 1 OF 1

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
01	1	01			
02	9	11			
03	4	04			
04	FMT	42			
05	π	56			
06	x→()	23			
07	e	12			
08	1	01			
09	8	10			
0a	6	06			
0b	FMT	42			
0c	π	56			
0d	↑	27			
10	1	01			
11	9	11			
12	2	02			
13	FMT	42			
14	π	56			
15	−	34			
16	x←()	67			
17	−	34			
18	6	06			
19	x	36			
1a	x←()	67			
1b	−	34			
1c	5	05			
1d	↑	27			
20	1	01			
21	9	11			
22	3	03			
23	FMT	42			
24	π	56			
25	x	36			
26	↓	25			
27	−	34			
28	1	01			
29	7	07			
2a	9	11			
2b	FMT	42			
2c	π	56			
2d	+	33			

Step	Key	Code	Display x	Display y	Display z
30	2	02			
31	2	02			
32	1	01			
33	FMT	42			
34	π	56			
35	÷	35			
36	1	01			
37	9	11			
38	4	04			
39	FMT	42			
3a	y→()	40			
3b	1	01			
3c	9	11			
3d	3	03			
40	FMT	42			
41	π	56			
42	x→()	23			
43	f	15			
44	e	12			
45	+	33			
46	2	02			
47	÷	35			
48	2	02			
49	1	01			
4a	8	10			
4b	FMT	42			
4c	π	56			
4d	x	36			
50	f	15			
51	+	33			
52	1	01			
53	9	11			
54	3	03			
55	FMT	42			
56	y→()	40			
57	f	15			
58	+	33			
59	2	02			
5a	÷	35			
5b	2	02			
5c	1	01			
5d	8	10			

Step	Key	Code	Display x	Display y	Display z
60	FMT	42			
61	π	56			
62	x	36			
63	1	01			
64	9	11			
65	2	02			
66	FMT	42			
67	π	56			
68	+	33			
69	1	01			
6a	9	11			
6b	2	02			
6c	FMT	42			
6d	y→()	40			
70	4	04			
71	2	02			
72	FMT	42			
73	GO TO	44			
74	END	46			
75					
76					
77					
78					
79					
7a					
7b					
7c					
7d					

Storage

Register	Contents
f	$\dot{\phi}_0$
e	$\ddot{\phi}_0$
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P_{42} CASE III PAGE 1 OF 2

Step	Key	Code	Display x	Display y	Display z
00	CONT	47			
1	2	02			
2	0	00			
3	0	00			
4	FMT	42			
5	π	56			
6	x→()	23			
7	e	12			
8	2	02			
9	2	02			
a	6	06			
b	FMT	42			
c	π	56			
d	x→()	23			
10	d	17			
1	↑	27			
2	2	02			
3	1	01			
4	6	06			
5	FMT	42			
6	π	56			
7	SIN X	70			
8	X	36			
9	2	02			
a	0	00			
b	4	04			
c	FMT	42			
d	π	56			
20	x⇄y	30			
1	−	34			
2	1	01			
3	8	10			
4	9	11			
5	FMT	42			
6	π	56			
7	SIN X	70			
8	X	36			
9	d	17			
a	↑	27			
b	2	02			
c	1	01			
d	6	06			

Step	Key	Code	Display x	Display y	Display z
30	FMT	42			
1	π	56			
2	cos x	73			
3	x	36			
4	1	01			
5	8	10			
6	9	11			
7	FMT	42			
8	π	56			
9	cos x	73			
a	x	36			
b	↓	25			
c	−	34			
d	2	02			
40	4	04			
1	5	05			
2	FMT	42			
3	π	56			
4	↑	27			
5	2	02			
6	0	00			
7	2	02			
8	FMT	42			
9	π	56			
a	x	36			
b	x	36			
c	↓	25			
d	y⇄()	24			
50	d	17			
1	x⇄y	30			
2	↑	27			
3	3	03			
4	2	02			
5	.	21			
6	2	02			
7	÷	35			
8	y⇄()	24			
9	d	17			
a	ROLL ↑	22			
b	x⇄y	30			
c	d	17			
d	x	36			

Step	Key	Code	Display x	Display y	Display z
60	2	02			
1	1	01			
2	0	00			
3	FMT	42			
4	π	56			
5	cos x	73			
6	x	36			
7	1	01			
8	8	10			
9	9	11			
a	FMT	42			
b	π	56			
c	cos x	73			
d	x	36			
70	↓	25			
1	−	34			
2	d	17			
3	÷	35			
4	2	02			
5	0	00			
6	0	00			
7	FMT	42			
8	y→()	40			
9	1	01			
a	9	11			
b	9	11			
c	FMT	42			
d	π	56			

Storage

f	$\dot{Y}_0$
e	$\ddot{Y}_0$
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Title LAUNCH SIMULATION P42 CASE III PAGE 2 OF 2

Step	Key	Code	Display x	Display y	Display z
8 0	x→()	23			
1	f	15			
2	e	12			
3	+	33			
4	2	02			
5	÷	35			
6	2	02			
7	1	01			
8	8	10			
9	FMT	42			
a	π	56			
b	x	36			
c	f	15			
d	+	33			
9 0	1	01			
1	9	11			
2	9	11			
3	FMT	42			
4	y→()	40			
5	f	15			
6	+	33			
7	2	02			
8	÷	35			
9	2	02			
a	1	01			
b	8	10			
c	FMT	42			
d	π	56			
a 0	x	36			
1	1	01			
2	9	11			
3	8	10			
4	FMT	42			
5	π	56			
6	+	33			
7	1	01			
8	9	11			
9	8	10			
a	FMT	42			
b	y→()	40			
c	2	02			
d	3	03			

Step	Key	Code	Display x	Display y	Display z
b 0	7	07			
1	FMT	42			
2	π	56			
3	↑	27			
4	2	02			
5	3	03			
6	6	06			
7	FMT	42			
8	π	56			
9	+	33			
a	.	21			
b	2	02			
c	+	33			
d	y→()	40			
c 0	−	34			
1	1	01			
2	+	33			
3	1	01			
4	2	02			
5	FMT	42			
6	GO TO	44			
7	END	46			
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

Section V. CONCLUSIONS

The programs presented herein can be utilized to obtain an idea of the stagnation temperatures and pressures that may be imposed on a launch tube and the surrounding area by a given rocket, the internal pressure in the launcher at the rocket nozzle exit, and the effects on missile and launcher actions of various dimensional offsets and misalignments and different firing positions. These programs are intended for use in design efforts and were written for the Hewlett-Packard 9100B to enable in-house efforts of this nature to be more efficiently realized.

It must again be stated that the results of these programs have not as yet been compared with actual data to determine accuracy.

REFERENCES

1. Prozan, R. J. and J. K. Lovin, An Analytical Method for Predicting Rocket Motor Blast Loads on a Launcher, U. S. Army Missile Command Report No. RL-TR-69-3, 6 October 1965.

2. Schlenker, G., Method of Determining Stagnation Temperature-Pressure Distribution in Exhaust Field of Rocket Using Underexpanded Convergent-Divergent Nozzle, Rock Island Arsenal TR 58-875, 21 April 1958.

3. Marshall, K. A., Computer Method of Determining Stagnation Temperature-Pressure Distribution of Exhaust Field of LITTLEJOHN, U. S. Army Missile Command Report No. RL-TN-64-2, 15 October 1964.

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